

The logo features a stylized white 'Q' on the left, followed by a series of white lines radiating from a central point to a circle on the right. Inside the circle is a white arrow pointing to the right.

Quantum Optics XI

⟨1-5 IX 2025⟩ Jagiellonian University
Kraków, Poland



UNIwersytet Jagielloński
w Krakowie



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The conference is co-financed from the state budget funds allocated by the Minister of Science and Higher Education (Poland) under the Excellent Science II program (project no: KONF/SP/0080/2024/02)

Dear Participants,

It is our great pleasure to welcome you to the **11th Quantum Optics Conference**. We are delighted to have you with us and hope you will feel at home both in Kraków and within the historic walls of the Jagiellonian University.

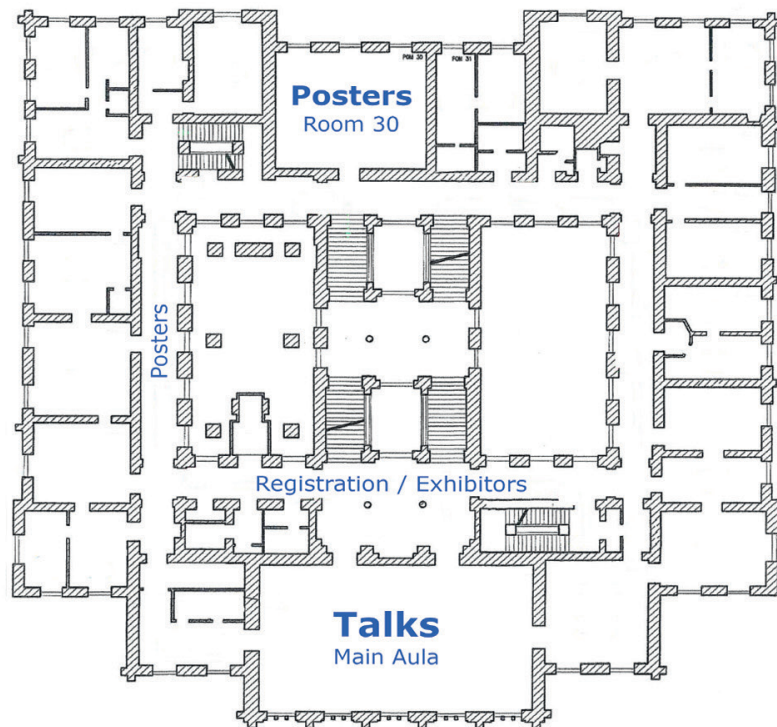
Held every four years since 1985, the Quantum Optics Conference began as a unique forum uniting scientists from both sides of the Iron Curtain. In the decades since, it has grown into a meeting devoted to quantum and nonlinear optics, cold-atom physics, and quantum information theory – in both their theoretical and experimental dimensions. Throughout its history, the conference has been enriched by the presence of world-class experts, ensuring its high scientific standard, as well as by numerous PhD students and early-career researchers for whom it has often been a gateway to a successful scientific journey.

This year's edition is a particularly special one: it marks the **40th anniversary** of the conference and its **first visit to Kraków**. To celebrate, we will gather in the historic lecture halls of Poland's oldest university, founded in 1364 – spaces once frequented by Polish kings and Nicolaus Copernicus himself. Many sessions will take place in these remarkable surroundings, while the Collegium Novum will host our lunches, coffee breaks, and poster sessions, offering the perfect setting for stimulating discussions and valuable connections.

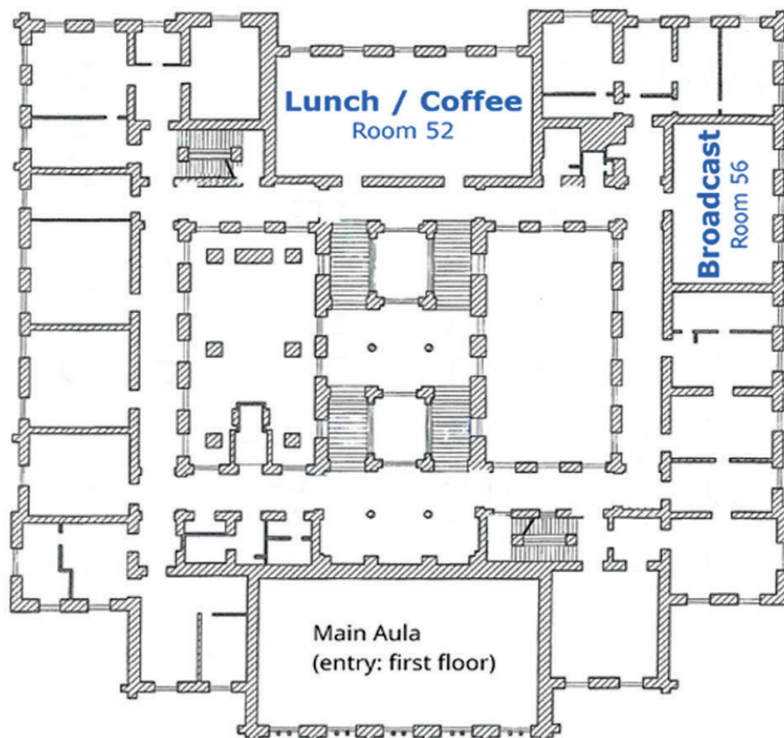
We are confident that the city of Kraków, with its rich cultural heritage and distinctive atmosphere, will provide unforgettable experiences to complement the scientific program.

We warmly welcome you and wish you a productive, engaging, and inspiring conference.

The Conference Organizers



First Floor



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Monday

09:00 am - 09:20 am	Opening
09:20 am - 10:00 am	Peter Zoller Quantum Material Design with Programmable Quantum Simulators
10:00 am - 10:40 am	Stefan Willitsch Quantum technologies for trapped molecular ions
10:40 am - 11:00 am	Max Bergerhoff Quantum repeater applications with two co-trapped 40Ca^+ ions
11:00 am - 11:30 am	Coffee break
11:30 am - 12:10 pm	Jun Ye Quantum science and clocks
12:10 pm - 12:50 pm	Michał Zawada Fundamental physics with ultra-stable optical cavities
12:50 pm - 01:10 pm	Vasiliy Makhalov In situ observation of supersolid dynamics in a spin-orbit-coupled Bose-Einstein condensate
01:10 pm - 02:40 pm	Lunch
02:40 pm - 03:20 pm	Morgan Mitchell Quantum sensing and quantum optics with extraordinarily coherent spin
03:20 pm - 04:00 pm	Maciej Kowalczyk Generation and applications of single-cycle mid-infrared laser pulses
04:00 pm - 04:20 pm	Jan Krzyżanowski Enabling hybrid two-photon interference with a time lens
04:20 pm - 04:50 pm	Coffee break
04:50 pm - 05:30 pm	Jan Chwedeńczuk Conveyor belt for quantum information
05:30 pm - 05:50 pm	Paweł Cieśliński Unmasking the Polygamous Nature of Quantum Nonlocality
05:50 pm - 06:10 pm	Karol Łukanowski Quantum Security of Optical Key Distribution
06:30 pm - 08:00 pm	Poster session



Poster Sessions

Michał Suchorowski	Mon – 1	Alberto Mercurio	Mon – 25
Tomasz Polak	Mon – 2	Filippo Ferrari	Mon – 26
Paweł Cieśliński	Mon – 3	Britton Hofer	Mon – 27
Sanu Kumar Gangwar	Mon – 4	Szymon Wójtewicz	Mon – 28
Danish Ali Hamza	Mon – 5	Lukas Klein	Mon – 29
István Márton	Mon – 6	Martin Bielak	Mon – 30
Karthik Eswaran	Mon – 7	Prosenjit Majumder	Mon – 31
Alexander Hodges	Mon – 8	Igor Bröckel	Mon – 32
Lewis Ruks	Mon – 9	Maksym Prodius	Mon – 33
Arpita Pal	Mon – 10	Ali Emami-Kopaei	Mon – 34
Jacek Dobrzyniecki	Mon – 11	Krzysztof Gawryluk	Mon – 35
Pedro Ruyter Nicácio Falcão	Mon – 12	Konrad Pawlik	Mon – 36
Anshuman Nayak	Mon – 13	Azadeh Ahmadian	Mon – 37
Razmik Aramyan	Mon – 14	Rajesh Chell	Mon – 38
Arkadiusz Kobus	Mon – 15	Anvesh Dixit	Mon – 39
Joanna Kalaga	Mon – 16	Laurent Longchambon	Mon – 40
Abhik Kumar Saha	Mon – 17	Matteo Marinelli	Mon – 41
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Rafał Bogaczewicz	Mon – 19	Dariusz Kierski	Mon – 43
Sanket Das	Mon – 20	Anna Musiał	Mon – 44
Agata Wojciechowska	Mon – 21	Seongho Shin	Mon – 46
Mikołaj Lasota	Mon – 22	Tomasz Karpiuk	Mon – 47
Julian Pick	Mon – 23	Ewelina Lange	Mon – 49
Scott Hubele	Mon – 24	Martina Zündel	Mon – 50

Monday



Bounded-Error Quantum Simulation via Hamiltonian and Lindbladian Learning

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Quantum simulators promise efficient solutions to complex many-body problems beyond classical capabilities. However, transforming these devices into reliable computational tools requires not only the estimation of observables but also the provision of rigorous, trusted error bounds. This is particularly critical for analog quantum simulators, which, despite their scalability and native implementation of target Hamiltonians, lack quantum error correction. We present a general framework for *bounded-error quantum simulation*, applicable across diverse platforms, and demonstrate its implementation in a trapped-ion analog quantum simulator performing real-time quench dynamics. Our protocol proceeds in two stages: First, we employ high-precision black-box learning to experimentally characterize the system's Hamiltonian and, where applicable, the Lindbladian governing Markovian dissipation, capturing statistical uncertainties via a Bayesian error model. Second, the simulator is used as a computational device to predict many-body observables, with rigorous error bounds derived from the uncertainties in the learned model. These bounds enable both verification in classically accessible regimes and trusted predictions beyond classical reach, thereby establishing a path toward quantitative, certifiable analog quantum simulation.

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Quantum technologies for trapped molecular ions

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Molecules are quantum systems of prime significance in a variety of contexts ranging from physics over chemistry to biology. In spite of their importance, the development of quantum technologies for molecules has remained a long-standing challenge due to their complex energy-level structures. Trapped molecular ions are particular attractive in this context as it is possible to observe, manipulate and control single isolated molecules under precisely controlled conditions. In the talk, we will highlight new experimental methods for the detection, preparation and manipulation of the quantum states of single trapped molecular ions and discuss applications of these techniques in the realms of precision molecular spectroscopy, quantum science and chemistry.

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Quantum repeater applications with two co-trapped $^{40}\text{Ca}^+$ ions

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The quantum repeater (QR) [1] is a fundamental building block for the realization of large-distance quantum networks. By dividing a transmission link into segments of entangled quantum memories and cells of asynchronously entangled photons [2], it is possible to overcome the exponential loss of direct transmission.

We report on the implementation of a quantum repeater cell with free-space coupled photons from two $^{40}\text{Ca}^+$ ions in the same Paul trap as memories. Ion-photon entanglement is generated asynchronously by controlled emission of single photons from the individually addressed ions into separate single-mode fibers. Photon-photon entanglement with 77.8(6)% average fidelity is then generated by a Mølmer-Sørensen gate and state projection on the ions. The advantage of this protocol is highlighted by a 100-fold improvement of the photon pair probability compared to a synchronously operated QR cell, resulting in a single-attempt probability of $9.76(2) \cdot 10^{-5}$ and a rate of $11.34(2) \text{ s}^{-1}$ for detecting a photon pair [3].

The QR segment is required to connect QR cells and to form a QR link. We show the implementation of a QR segment in the same setup with two $^{40}\text{Ca}^+$ quantum memories that are entangled by entanglement swapping of free-space coupled single photons after previously generating ion-photon entanglement as shown in Fig. 1 (a). Entanglement of the two memories is proven by a parity measurement using two $\pi/2$ rotation pulses on the ions after photonic coincidence detection. The parity oscillation displayed in Fig. 1 (b) shows a peak-to-peak value of 1.6(1), while a value larger than one is sufficient to prove entanglement [4]. We achieved an entanglement rate of 2.61 per hour.

In preparation for quantum repeater applications in the real world, quantum communication protocols including photon-photon entanglement, ion-photon entanglement and quantum state teleportation using a parametric down-conversion source of entangled photon pairs and a single $^{40}\text{Ca}^+$ ion in combination with polarization-preserving quantum frequency conversion from the ionic wavelength to the telecom C-band, as well as polarization compensation, have been demonstrated over the 14.4 km Saarbrücken urban fiber link which is shown in Fig. 1 (c) [5].

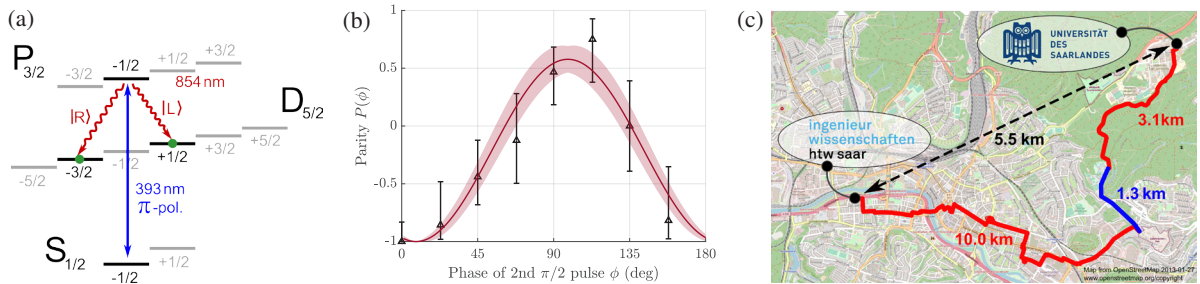


Fig. 1: (a) Relevant level scheme of the $^{40}\text{Ca}^+$ ion with Zeeman sublevels for generation of ion-photon entanglement, showing excitation and emission paths. (b) Parity measurement in dependence of the phase of the second $\pi/2$ pulse. Measured data points are shown in black. The red line is a sinusoidal fit with its uncertainty as red shading. (c) Map of the fiber link across Saarbrücken [5].

In this context, a new ion trap setup with integrated sub-mm cavity for increased generation and collection probability of the photons is presented. It will improve the scaling behavior of the QR cell and enables quantum repeater protocols over the fiber link despite the losses of the link. It will also allow to macroscopically separate the memories by individually trapping ions in different traps for full realization of a QR segment.

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Quantum system engineering for clocks and fundamental physics

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Laser and quantum sciences have fueled revolutionary developments in atomic, molecular, and fundamental physics. Quantum state engineering and many-body physics are providing coherent quantum systems at increasingly large sizes, revolutionizing the performance of clocks and metrology and promising new discovery opportunities. Quantum technology has brought many thousands of atoms to minutes-long coherence times, it is now also knocking on the door of nuclear physics, heralded by the recent breakthrough of quantum-state-resolved laser spectroscopy of thorium-229 nuclear transition. These progresses in quantum metrology provide new tools for quantum sensing, and raise the prospect of using quantum sensors to search for new physics beyond the standard model and probe the interface of gravity and quantum mechanics.

Fundamental physics with ultra-stable optical cavities

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Table-top-size ultra-stable Fabry-Pérot optical cavities from the state-of-the-art optical atomic clocks provide data that can be post-processed in search for various fundamental physics phenomena, and also for new physics beyond the standard model. Here, I present two examples: detecting gravitational waves [1] and testing hypothesis of space-time fluctuations [2].

The first generation of gravitational waves (GWs) detectors was based on mechanical resonance in large aluminium cylinders triggered by a gravitational wave flying through the detector [3]. These types of GWs detectors, so-called Weber bars, were operating connected in a worldwide network. Unfortunately, despite superb stable operation and perfect reduction of noises in the resonant-mass bar detectors, so far, there is no evidence of GWs events observed by acoustic resonance [3].

Optical cavities from optical atomic clocks can serve as bar GWs detectors for frequencies higher than 2 kHz. The 2-20 kHz range of the GWs spectrum can be accessed with instruments less than 2 metres in size. The materials and properties of the proposed cavities are in the grasp of today's technology. The ultra-stable optical cavities allow detection not only of predicted gravitational wave signals from such sources as binary neutron star mergers and post-mergers, subsolar-mass primordial black-hole mergers, and collapsing stellar cores but also of new physics beyond the standard model, looking for ultralight bosons such as QCD axions and axion-like particles formed through black hole superradiance.

It is expected that both the relativistic theory of gravity and quantum mechanics fail to describe physical phenomena at the Planck scale [5,6]. Many theories that unify these two forces propose that spacetime experiences quantum fluctuations at the smallest feasible distances [7,8]. This inherent fuzziness, sometimes called space-time foam, fundamentally restricts the precision of length measurements, potentially limited to the Planck length l_P [9,10]. As a consequence, the ultimate constraint in distance measurements should be attributed to quantum-gravity-induced fluctuations, and that also applies to frequency stability of the ultra-stable Fabry-Pérot optical cavity mode [11]. Therefore, knowledge of the noise budget of a set of independent ultra-stable optical cavities gives the limit for the quantum-gravity-induced amplitude fluctuation.

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In situ observation of supersolid dynamics in a spin-orbit-coupled Bose-Einstein condensate

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Spin-orbit-coupled Bose-Einstein condensates are a versatile experimental platform to engineer quantum many-body systems. In particular, they host the so-called stripe phase - an instance of a supersolid phase of matter. This exotic phase breaks both the gauge and continuous translational symmetries and features a peculiar excitation spectrum. The stripe phase appears as a superfluid with one-dimensional density modulation - a series of stripes. Both the in situ observation of density modulation and the excitation spectrum of the stripe phase have so far remained out of experimental reach.

Here we report on achieving these goals. We prepared a mixture of Bose-Einstein condensates of two spin states of potassium (^{41}K), coupled via a two-photon Raman transition. By harnessing the tunable interaction properties of ultracold ^{41}K , we realized a stable stripe phase that persists at coupling regimes with strong density modulation contrast. Using a matter-wave lensing technique to magnify the density pattern, we achieved in situ imaging of the stripes. We excited the collective modes of the system by quenching the Raman coupling strength. This allowed us to address both superfluid and crystal-like aspects of supersolids. Namely, we observed particle flow between the stripes as well as a stripe compression mode - an oscillation of the density modulation period - which unambiguously demonstrates the compressibility of the crystalline structure. We located the phase transition from the supersolid to an unmodulated superfluid through frequency softening of the compression mode. Moreover, by exploiting the Feshbach resonances of ^{41}K , we were able to tune the interactions in the system and shift the phase transition point. Our results establish spin-orbit-coupled supersolids as a powerful platform for exploring supersolidity and its rich dynamics.

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How well does quantum physics allow us to measure weak fields ?

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Fundamental physics has motivated much work in quantum optics, for example generation of squeezed light to use in interferometric gravitational wave detectors and deep studies of the problem of phase estimation, often described as the core problem of quantum sensing. In the post-Higgs era, fundamental physics increasingly employs precision measurements to search for physics beyond the Standard Model. This motivates work on precise detection of weak fields, which can signal the existence of as-yet-undetected particles and forces. Detection of the magnetic field is a paradigmatic example of field detection, for which there is abundant practical experience and - for specific sensors - model-based quantum sensitivity limits. These field-sensing limits look very different from phase estimation limits: . For example, color-centre ensembles [1] and atomic vapors [2] are known to have sensitivity limited by the *volume* of the region over which the sample is measured, with no dependence on a quantum information resource like particle number. For dc-SQUIDs, a similar limit concerns the *area* over which the flux is measured [3]. Until recently, all demonstrated dc field sensors obeyed a geometric limit of this kind, see Figure 1. I will describe what is and is not known about such limits [4], describe recent work on exotic sensor technologies without such limits [5] and a planned experiment to apply an exotic field sensor to searches for new physics [6].

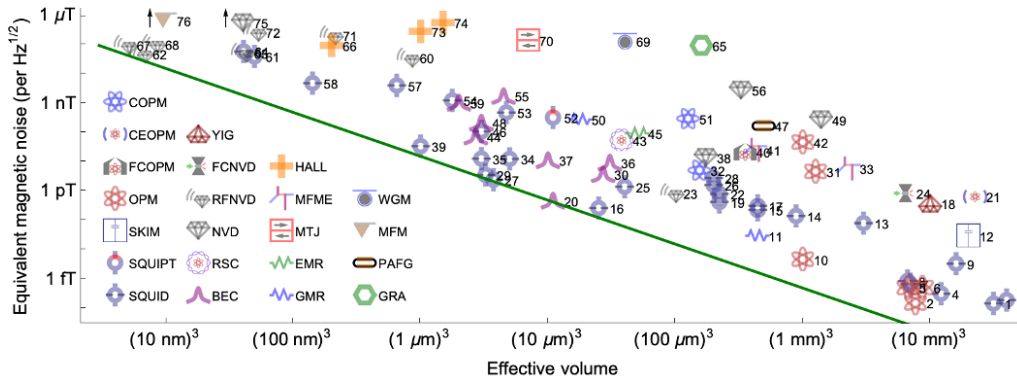


Fig. 1: Demonstrated magnetic sensitivities for “dc” field sensing (defined here as sub-kHz) and effective volume V of the sensed region, for a variety of technologies adapted from Palacios et. al. *Rev. Mod. Phys.* 2020 [4]. The green line shows the so-called “energy resolution limit” $E_R \equiv \langle \delta B^2 \rangle VT / 2\mu_0 = \hbar$, where $\langle \delta B^2 \rangle$ is the mean-squared error of the measurement, T is the duration, and μ_0 is the permeability of free space.

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Generation and applications of single-cycle mid-infrared laser pulses

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Quantum optics has traditionally been associated with experiments involving weak optical fields, often limited to a few-photon regime. However, recent studies have demonstrated that macroscopic quantum states of light can be generated with intensities high enough to drive extreme nonlinear processes. Notably, the high-harmonic generation driven by a bright squeezed vacuum [1] and the observation of quantum effects in attosecond science [2] suggest that laser sources producing ultrashort laser pulses comprising of a mere few cycles of electric field [3] can open new frontiers in quantum optics. The workhorse for these breakthrough experiments has been a Ti:sapphire laser technology, which, however, is inherently limited to the near-infrared spectral range. Here, we present a source of controllable single-cycle mid-infrared (mid-IR) laser pulses based on Cr:ZnS/Se lasers, often referred to as the "Ti:sapphire of the mid-IR" [4]. This technology provides a promising platform for exploring ultrafast quantum phenomena in the longer wavelength domain.

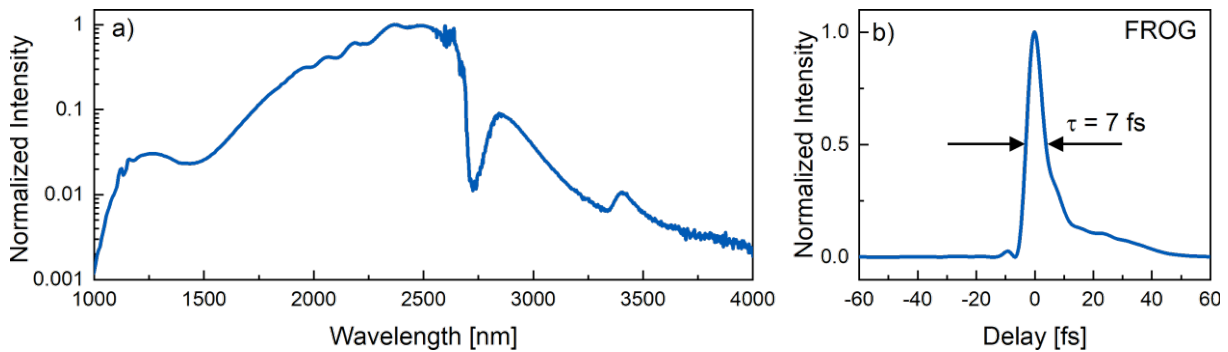


Fig. 1: (a) Optical spectrum and (b) temporal pulse profile measured by a frequency-resolved optical gating technique (FROG).

Our laser source is based on a Kerr-lens mode-locked Cr:ZnS laser oscillator delivering 30 fs pulses at 25 MHz repetition rate. We reached an average power of 650 mW with a record-low relative intensity noise ($\text{RIN} < 0.005\%$) stemming from an optimized pump source [5]. The oscillator output was spectrally-broadened to a two-octave-spanning bandwidth (Fig. 1a) in a single TiO_2 plate without the need for pre-amplification, which allowed to maintain ultralow noise operation. After the broadening stage, the pulses can be temporally compressed by dielectric dispersive mirrors down to 7 fs, a duration equivalent to a single electric field oscillation at the central wavelength of $2.3 \mu\text{m}$ [6] (Fig. 1b). Subsequently, the laser was actively stabilized to a carrier-envelope phase (CEP)-stable frequency comb. We propose a novel approach for CEP-stabilization based on an intracavity Pockels modulator, which allowed us to reach an unprecedented phase stability with sub-5-attosecond jitter. The output of our low-noise frequency comb producing single-cycle mid-infrared light pulses can be harnessed for further nonlinear down-conversion into the longer wavelength range down to $12 \mu\text{m}$ [7] with potential applications in field-resolved spectroscopy of biological samples [8]. Given its technical capabilities, we believe that single-cycle Cr:ZnS/Se lasers can become a true successor to the Ti:sapphire laser technology, offering a unique tool also for advancing ultrafast quantum optics into the mid-IR domain.

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Enabling hybrid two-photon interference with a time lens

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Single-photon indistinguishability is a crucial property for many photonic quantum technologies, as it affects the visibility of two-photon interference [1], which is used for e.g., entanglement swapping or quantum teleportation. It is critical for quantum information exchange between mismatched systems, like different photon source types [2].

Narrowband spectral filtering is commonly employed to restore the photon's indistinguishability, correcting the physical properties of single photons [2]. However, the filtering significantly decreases the number of counts. Alternatively, an electro-optic time lens [3] was shown to enable efficient single photon pulse modification.

Here we show, for the first time, non-classical interference effect with spectral-bandwidth-converted photons. We present a simplified experimental setup in Fig. 1(a). We start from two independent, bandwidth-mismatched photons, generated by a spontaneous parametric downconversion (SPDC) source and spectral filtering of one photon from the pair. The spectra at this stage of experiment are presented in Fig. 1(b). The visibility of Hong-Ou-Mandel (HOM) interference for those spectra is $(4.2 \pm 1.9)\%$. We present the measured HOM dip in Fig. 1(d).

We applied the time lens-based bandwidth converter to the other, spectrally broadband, photon. It compressed the spectrum by approximately a factor of 10 to match it to the spectrum of the narrowband photon. The measured spectra at this stage of experiment are presented in Fig. 1(c). After applying the converter we observed a HOM dip with visibility of $(63.2 \pm 1.9)\%$, presented in Fig. 1(d). It shows that matching the bandwidths of the interfering photons improved two-photon interference visibility from almost no visibility $((4.2 \pm 1.9)\%)$ to above the non-classical threshold of 50%. Moreover, the transmission of the converter is about 10 times higher than that of the employed spectral filter, highlighting the advantageous efficiency of the time lens-based converter.

The presented solution enables to efficiently integrate mismatched quantum systems, making a step towards entangling photons from different sources and building vast quantum networks. Also it may be used to improve the efficiency of photonic quantum computing, communication and sensing techniques that rely on HOM interference.

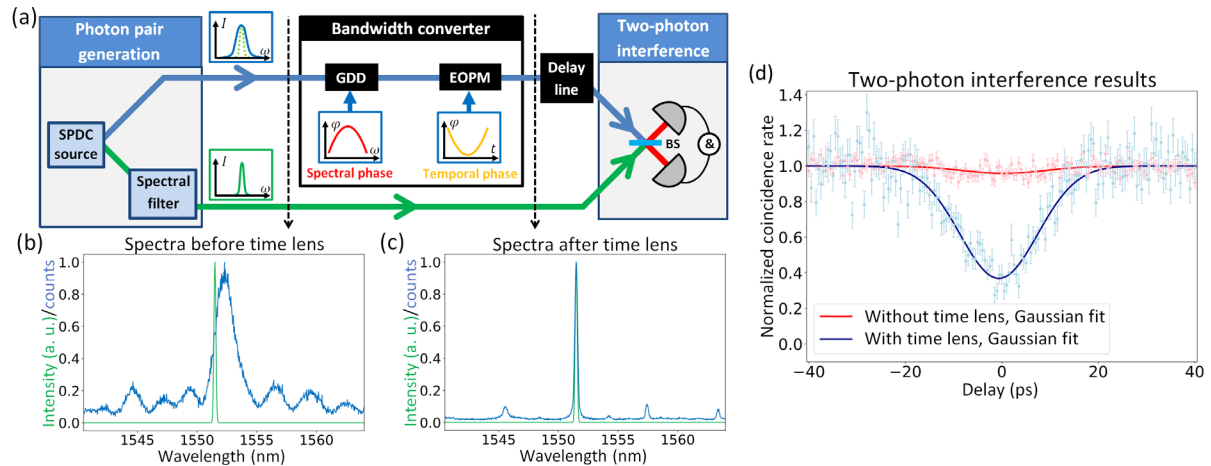


Fig. 1: Simplified schematic of the experimental setup (a). Blue, green and red lines indicate fiber connections. A photon pair is produced by the SPDC source, one photon is spectrally filtered. The photons' spectra at this stage of experiment are presented in (b). The second, broadband photon is spectrally compressed using the time lens based bandwidth converter. It applies a quadratic spectral phase using group-delay-dispersion (GDD) medium and a quadratic temporal phase with an EOPM (electro-optic phase modulator). We drive the EOPM with an RF signal from an arbitrary waveform generator amplified by an RF amplifier (not shown). The measured spectra after the converter are presented in (c). We perform two-photon interference at a 50:50 fiber beam splitter (BS). (d) Results of HOM interference: normalized coincidence rates between two beam splitter outputs as a function of relative delay between the interfering photons, set by a delay line. Hong-Ou-Mandel dip after compressing the photon (for spectra presented in (c)), blue; the dip without the bandwidth converter (for spectra presented in (b)), red.

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Conveyor belt for quantum information

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This talk is focused on a lossless transfer of information across a many-body system. It will be shown that a single qubit can play the role of an antenna that gathers vast amounts of information from a complex system. A condition will be formulated under which the antenna, far apart from the source and embedded in a many-body interacting medium, can still collect the complete information. A striking feature of this setup is that a single-qubit antenna can accommodate even the full signal amplified by the entanglement of the source. In consequence, the retrieval of this information can be performed with simple one-qubit operations on the antenna (which will be fully characterized) rather than multi-qubit measurements of the source. Finally, the control over the system parameters that is necessary for lossless signal propagation, will be discussed.

Monday

Unmasking the Polygamous Nature of Quantum Nonlocality

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Quantum nonlocality is one of the most intriguing features of quantum theory. Beginning with the famous EPR argument [1], continuing through the pioneering works of John Bell [2], and extending to various experiments [3-6], it reveals the impossibility of a local-realistic description of quantum phenomena. The violation of a Bell inequality now serves not only as a fundamental test of statements about the nature of reality but also finds applications in many areas of modern quantum technologies. One crucial concept in the study of quantum nonlocality is the monogamy principle, which states that it is impossible to simultaneously violate all k -partite ($k < N$) two-setting Bell inequalities among N different parties.

Following the early findings by Scarani and Gisin [7], and later by Toner and Verstraete [8-9], this principle became a fundamental result in the field. For three parties (A, B, C), Bell monogamy is well established: if one pair of observers (A, B) violates the CHSH inequality, simultaneous violation by the pair (B, C) is impossible. This result is commonly referred to as monogamy.

However, as shown in this work, the monogamy principle is not a fundamental law. Instead, it is merely a consequence of the specific mathematical structure of certain inequalities, which are not universal. To support this claim, we develop a systematic method for constructing Bell inequalities among $N - 1$ observers that do not obey to the monogamy principle for all $N > 3$. Using permutation symmetry, we find that for $N \geq 5$, Mermin inequalities [10] can be simultaneously violated across all $(N - 1)$ -qubit subsystems, with the effect increasing exponentially with N . Even for $N = 4$, we identify a three-qubit inequality that allows for simultaneous violation in all three-party subsystems. Furthermore, we present an intriguing minimalistic polygamous scenario, based solely on bipartite correlations between all pairs of observers. We show that the simultaneous violation of all inequalities is possible when the number of parties is $N = 18$.

Recognizing the practical challenges associated with generating high-fidelity quantum states in experimental setups, we identify inequalities that are violated experimentally by noisy six-qubit Dicke states [11-12]. Thus, the polygamous nature of quantum nonlocality is both theoretically proven and experimentally confirmed.

For the full manuscript, see [13].

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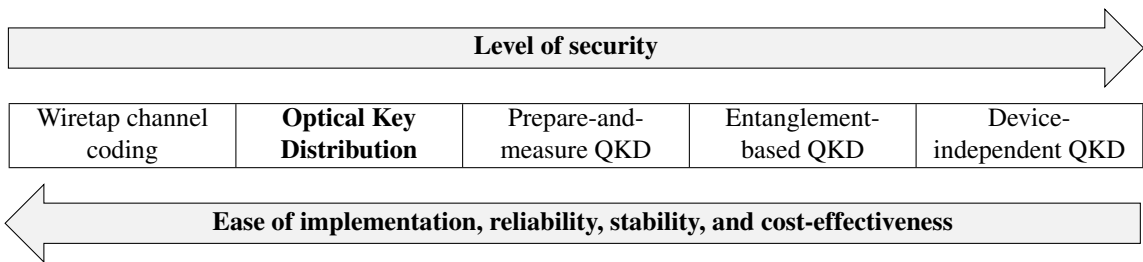
Quantum Security of Optical Key Distribution

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Protection of data transmission from unauthorized third-party access is of paramount importance in the modern, information-driven era, and yet the physical layer of most communication systems remains susceptible to attacks and eavesdropping. Security measures are instead delegated to digital encryption techniques, based on the belief that certain mathematical problems are difficult to solve. These, however, may eventually break — either with the advent of large-scale quantum computing or the invention of better classical algorithms. To remedy that, several techniques have been developed to ensure data protection already at the level of the physical communication channel, some of which are listed below.



Tab. 1: Physical layer security techniques.

The crown jewel of physical layer security is Quantum Key Distribution (QKD), whose goal is to generate identical, secret, and random bit sequences between two distant users. Such *keys* may later be used to implement mathematically secure private key cryptography or to seed functioning digital encryption. The excellent security of QKD stems from quantum entanglement and the no-cloning theorem for quantum states — which, at the same time, makes it difficult to realize experimentally and even harder to implement in the existing information infrastructure, due to the need for high-fidelity quantum state preparation, single photon detection, or shot-noise-limited coherent detection.

In recent years, Optical Key Distribution (OKD) has emerged as an attractive alternative to QKD [1,2] for shared randomness generation. OKD augments physical layer security by taking advantage of the inherent shot noise present in the photodetection process. The protocol is realized with intensity modulation and direct detection only, making it suitable for implementation in the standardized telecommunication architecture. Moreover, the scheme is compatible with simultaneous data transmission [3] and its low complexity allows for versatile use — not only in optical fiber links, but in free-space transmission as well. The latter makes it a promising candidate for safeguarding satellite networks [4] or even deep-space communication [5], both of which face stringent SWaP (size, weight, and power) constraints.

The security level of OKD is diminished with respect to QKD due to the additional assumption that the potential malicious eavesdropper acts only passively in the channel, i.e., may collect a portion of the transmitted signal, but does not interfere with the part that reaches the honest recipient. Passive eavesdropping is the most immediate threat to data secrecy and covers scenarios such as collection of light leakage from optical fibers or an enemy telescope capturing part of an optical beam that diverges out of a secured receiver perimeter due to diffraction. By careful use of post-selection, the rate of key generation is provably positive even when the fraction of the signal stolen by the adversary exceeds that received by the honest party. Moreover, while previous security proofs assumed that the eavesdropper also implements direct detection, we have now extended the proof to the most general quantum passive eavesdroppers — i.e., ones performing minimal-error Helstrom measurements on the collected signal, or even optimal collective measurements that saturate the Holevo bound for accessible information [6].

This presentation will cover the physical layer security landscape, introduce the OKD protocol, discuss the tradeoff between security and implementability, and characterize the quantum security of the scheme.

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Tuesday

09:00 am - 09:40 am	Luis Santos Dipolar lattice gases in optical ladders
09:40 am - 10:20 am	Michał Karpiński Shaping of quantum light pulses for applications in quantum networks and beyond
10:20 am - 10:40 am	Titus Franz High-Fidelity Entangling Gates and Strong Correlations in a Fermi-Hubbard Quantum Simulator
10:40 am - 11:00 am	Piotr Deuar Self organisation and metastability of cavity bosons beyond the adiabatic elimination approximation
11:00 am - 11:30 am	Coffee break
11:30 am - 12:10 pm	Derek Jackson Kimbal Tests of Fundamental Physics with Spin-based Sensors
12:10 pm - 12:50 pm	Jacek Dziarmaga 2D tensor networks for quantum simulation
12:50 pm - 01:10 pm	Daniel Gavilan-Martin Searching for dark matter with atomic Rb-K-3He comagnetometers
01:10 pm - 02:40 pm	Lunch
02:40 pm - 03:20 pm	Yanbei Chen The Role of Quantum Measurements in Experimental Tests of Quantum Gravity
03:20 pm - 04:00 pm	Roman Ciuryło Optical metrology of molecular systems
04:00 pm - 04:20 pm	Tomasz Paterek Non-classical mediators and gravitational entanglement
04:20 pm - 04:50 pm	Coffee break
04:50 pm - 05:30 pm	Mikhail Lukin Exploring quantum computing frontier with programmable atom arrays
05:30 pm - 05:50 pm	Andrzej Opala Large Scale Quantum Optical Neural Networks in a Phase-Space Framework
05:50 pm - 06:10 pm	Maria Hernandez Ruiz Cavity-enhanced atomic magnetometer for micro-bio-magnetic measurements
06:30 pm - 08:00 pm	Poster session



Poster Sessions

Saurabh Gupta	Tue – 1	King Lun Ng	Tue – 24
Indranil Maiti	Tue – 2	Hana Medhat	Tue – 25
Domantas Burba	Tue – 3	Julia Bergmann	Tue – 26
Franz Von Silva-Tarouca	Tue – 4	Francis Bayocboc	Tue – 27
Jamie Morley	Tue – 5	Ksawery Mielczarek	Tue – 28
Matheus Eiji Ohno Bezerra	Tue – 6	Vardhan Thakar	Tue – 29
Nils Krause	Tue – 7	Niladri Modak	Tue – 30
Sreeshna Subhash	Tue – 8	Wenjing Zhou	Tue – 31
Justyna Stefaniak	Tue – 9	Nur Fadhillah Binti Rahimi	Tue – 32
Tomohiro Yamazaki	Tue – 10	Marcin Koźbial	Tue – 33
Vaibhav Mahendrakar	Tue – 11	Daniel Derr	Tue – 34
Akhil Ayyadevara	Tue – 12	Patrik Schach	Tue – 35
Michal Neset	Tue – 13	Marcin Karczewski	Tue – 36
Krishna Nand Trivedi	Tue – 14	Sanjay Kapoor	Tue – 37
Lorenzo Papa	Tue – 15	Liyang Qiu	Tue – 38
Zbigniew Ficek	Tue – 16	Piotr Maslowski	Tue – 39
Francesco Atzori	Tue – 17	Christian Niehof	Tue – 40
Vojtech Kala	Tue – 18	Miao Cai	Tue – 41
Daniel Benedicto Orenes	Tue – 19	Laura Ellis	Tue – 42
Kuntal Samanta	Tue – 20	Anita Dąbrowska	Tue – 43
Ivor Kresic	Tue – 21	Maxime Lecomte	Tue – 45
Ishan Varma	Tue – 22	Sarah Waddington	Tue – 46
Neven Šantić	Tue – 23	Karolina Słowik	Tue – 47

Tuesday



Dipolar lattice gases in optical ladders

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Dipolar gases in optical lattices offer an excellent platform for the study of the ground-state properties and dynamics of lattice models with strong inter-site interactions. In this talk, I will focus in particular on two-leg ladder models, which constitute an intermediate regime in between one- and two-dimensional systems. I will consider three concrete scenarios, which may be implemented in experiments, in particular with polar molecules, in which the dipole-dipole interactions result in qualitatively new physics. In the first one, I will show how tilting a square ladder along the rung direction may allow for the observation of a topological quantum floating phase in an effective XXZ model [1]. This phase is a topological Luttinger liquid which presents an incommensurate density modulation. I will then discuss the case of polar molecules pinned in a triangular ladder array. I will show that under currently available experimental conditions, a proper engineering of the lattice orientation and the polarizing electric field may result in a rich ground-state physics, including chiral Luttinger liquids, as well as interesting non-equilibrium dynamics [2]. Finally, I will discuss how dipolar spin models in square ladder arrays present a counter-intuitive dynamics, characterized by an intriguing long-lasting partially-relaxed pre-thermalization regime in which the system is partially localized and partially equilibrated [3].

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Shaping of quantum light pulses for applications in quantum networks and beyond

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Spectral-temporal modes of quantum light have been recognized as a promising platform for quantum information processing (QIP) and metrology [1,2]. Coherent modification of single-photon pulsed spectral-temporal modes is necessary to enable efficient matching between emitters and absorbers in a quantum network scenario. This is due to an orders-of-magnitude mismatch between timescales and spectral bandwidths of quantum emitters. I will discuss experimental tools to efficiently modify the timescale and spectral bandwidth of single-photon pulses based on the concepts of temporal imaging, time-to-frequency and frequency-to-time conversion [2]. We show efficient spectral bandwidth modification by more than 2 orders of magnitude, from few picosecond single-photon pulses compatible with standard telecommunication channels to sub-500 MHz spectral bandwidths, compatible with matter-based quantum information processing platforms [3]. I will discuss the prospects and limitations towards more significant spectral-temporal modifications.

These techniques can be used to manipulate the timescale of second order correlation function [4]. We show electro-optic temporal imaging of time-resolved second-order coherence function at single-picosecond timescales. We use temporal magnification by a factor of 520 to measure maximal bunching of picosecond pulsed multimode thermal light. We report measurement of normalized second order correlation function of 2.02 ± 0.05 by reducing the temporal sampling intervals to below 3.5 ps. This technique may enable new advancements in applications of intensity correlation measurements, in particular in astronomy and quantum photonics.

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High-Fidelity Entangling Gates and Strong Correlations in a Fermi-Hubbard Quantum Simulator

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Quantum simulations with ultracold atoms have opened a new frontier for exploring strongly correlated quantum systems, providing insights into phenomena such as the pseudogap [1] and high-temperature superconductivity.

In this talk, I will present how we leverage optical superlattices within our quantum gas microscope to precisely control the phase and tunneling of atoms confined in isolated double wells—the essential building blocks for digital fermionic quantum computation [2]. Within these double wells, we realize two-particle entangling $\sqrt{\text{SWAP}}$ -gates with over 100 fermions, achieving a fidelity of 99.8%, and demonstrate that the entangled state remains coherent for over 10 seconds [3]. Additionally, we demonstrate how tailored pulse sequences can disentangle spin-exchange dynamics from coherent doublon-hole tunneling, an essential capability for constructing the gate fabrics relevant to quantum chemistry [4].

When combined with analog simulation of the Fermi-Hubbard model, these gates will enable access to novel observables, such as coherent pairing correlations, at the microscopic level, and offer a new perspective on the fundamental properties of the pseudogap or of mixed-dimensional systems [5].

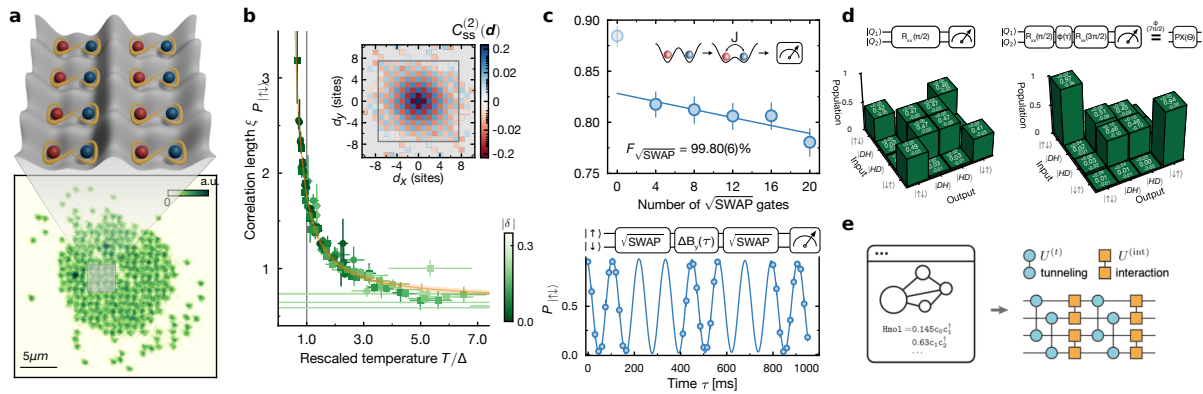


Fig. 1: The Lithium Quantum Gas Microscope. **a** Single-site resolved image of ultracold lithium atoms loaded into an optical superlattice. **b** Exponential dependence of the correlation length ξ as a function of temperature. ξ is extracted from spin-spin correlation measurements of the antiferromagnetic order (inset). Rescaling the temperature with a doping-dependent energy scale Δ reveals a universal scaling law. **c** In each double well of the optical superlattice, we perform entangling $\sqrt{\text{SWAP}}$ -gates using superexchange interactions J . By repeatedly applying the gate, we extract a fidelity of 99.8%. The coherence of the entangled state created by the $\sqrt{\text{SWAP}}$ -gate is characterized via singlet-triplet oscillations, revealing a lifetime exceeding 10 seconds. **d** While the natural gate leads equally to spin-exchange and coherent doublon-hole tunneling, these two processes can be separated by a pulse sequence. The resulting effective gate is a building block for quantum chemistry (**e**).

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Self organisation and metastability of cavity bosons beyond the adiabatic elimination approximation

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Phase-space formulations of quantum mechanics like the positive-P and truncated Wigner can give access to the full quantum behaviour of very large systems. In particular, the full distribution of single-shot configurations can be obtained from a stochastic simulation. This is particularly useful for dissipative systems for which direct simulation is harder but phase space methods become stable [1].

In a recent work [2] we have looked at the very long-time behaviour and self-organisation of weakly interacting bosons in a 2d optical lattice coupled to a lossy cavity, in the regime of high filling similar to experiments at ETH [3]. The truncated Wigner representation allows us to go orders of magnitude longer in time compared to earlier numerical work. It takes into account the dynamics and correlation of the cavity mode, quantum fluctuations, and self-organisation of individual runs, and has been benchmarked by us for this system.

We observe metastability at very long times and superfluid quasi-long range order, in sharp contrast with the true long range order found in the ground state of the Bose-Hubbard model with extended interactions obtained by adiabatically eliminating the cavity. The metastability appears to be dependent on the relaxation of the adiabatic elimination constraint. As the strength of the cavity coupling increases in a superfluid, the system first becomes (lattice) supersolid at the superradiant transition and then turns into a charge-density wave via the BKT mechanism. Notably, experimental preparation times have often been comparable with the very long times simulated here, so the metastable effects may be relevant in practice.

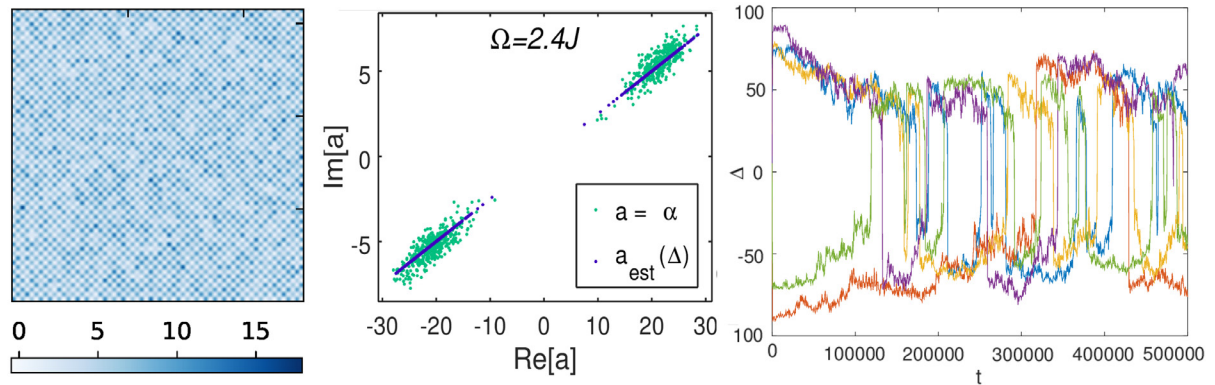


Fig. 1: Behaviour of a self-organised lattice supersolid of 2d cavity bosons. Left: checkerboard density pattern; Centre: cavity field amplitudes in the full quantum simulation (turquoise) and adiabatic elimination approach (blue); Right: checkerboard order parameter Δ for several runs over long times. Note the slow bistable switching after reaching the long-time ensemble [2].

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Tests of Fundamental Physics with Spin-based Sensors

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Novel interactions beyond the four known fundamental forces in nature (electromagnetic, gravitational, strong and weak interactions) may arise due to beyond-the-standard-model physics [1,2], manifesting as discrete-symmetry-violating electromagnetic moments correlated with particle spins [3], exotic spin-dependent forces [4], and coupling of spins to ultralight bosonic dark-matter fields [5]. Experimental methods and technologies developed for spin-based quantum sensors have rapidly advanced in recent years, and these tools enable increasingly precise control and measurement of spin dynamics [6]. Thus spin-based quantum sensors enable new ways to search for myriad exotic physics phenomena, and offer a methodology to test fundamental physics that is complementary to particle colliders and large-scale particle detectors.

In this talk, we highlight several ongoing and proposed experiments searching for beyond-the-standard-model physics using atomic magnetometers and comagnetometers [7-11], nuclear magnetic resonance [12], precision atomic spectroscopy [13,14], and levitated precessing ferromagnets [15-18].

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Tensor networks for quantum simulation

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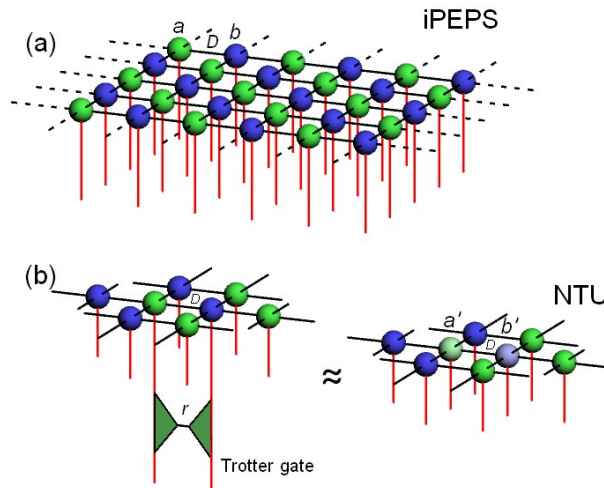


Fig. 1: Panel (a) shows PEPS tensor network on an infinite square lattice. Here every ball is a rank-5 tensor. Its red line is a physical indices numbering states in a computational basis at its site. The black lines are virtual indices contracting tensors at nearest-neighbor (NN) lattice sites. They carry entanglement across the system. Their (bond) dimension D is a refinement parameter limiting the amount of allowed entanglement. Panel (b) shows application of a NN Trotter gate to the state during a trotterized real/imaginary time evolution.

I will make a brief introduction to tensor network (TN) states and algorithms that became a method of choice for strongly correlated quantum many body systems on a lattice in one and two dimensions. I will emphasize the 2D TN known as PEPS (pair-entangled projected state) and its two recent applications to unitary time evolution and thermal Gibbs states.

One is the recent quantum computational advantage demonstration with the coherent D-Wave quantum annealer [1], where TN served, on the one hand, as a benchmark for the quantum simulator and, on the other hand, as the most competitive classical method that, nevertheless, in the end failed the competition with the quantum hardware.

The other is tensor network simulation of finite temperature states in the Hubbard and $t - J$ models – the two paradigmatic models of high- T_c superconductivity – that proved notoriously hard to solve analytically/numerically and, therefore, are subject to intensive experimental effort in the ultracold atoms community aiming at their quantum simulation. I will present some PEPS results [2,3] down to temperatures of one tenth of the hopping rate, in the pseudogap regime. These results, obtained directly in the thermodynamic limit, can serve as a guide/benchmark for the current experimental efforts.

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Searching for dark matter with atomic Rb-K- ^3He comagnetometers

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Self-compensated comagnetometers, employing overlapping samples of spin-polarized alkali and noble gases (for example K- ^3He) are promising sensors for exotic beyond-the-standard-model fields and high-precision metrology such as rotation sensing. We propose and demonstrate a general method to calibrate the response of an atomic comagnetometer, to any possible perturbation of the atomic spins. The method uses a convenient, easy-to-implement protocol that is experimentally verified by successfully using it to predict the comagnetometer response to rotations [1].

We use this method to calibrate our sensitivity to an Axion-like particle (ALP) dark matter search. We search through the ALP-nucleon interaction by interfering the signals of two atomic K-Rb- ^3He comagnetometers, with one situated in Mainz, Germany, and the other in Kraków, Poland [2]. ALPs arise from well-motivated extensions to the Standard Model and could account for dark matter. ALP dark matter would manifest as a nearly monochromatic field oscillating at an as of yet unknown frequency. The frequency depends on the ALP mass, which could plausibly range from $10^{-22} \text{ eV}/c^2$ to $10 \text{ eV}/c^2$. The search extends over nine orders of magnitude in ALP mass. In this range, no significant evidence of an ALP signal is found. We thus place new upper limits on the ALP-neutron, ALP-proton and ALP-electron couplings reaching below $g_{aNN} < 10^{-9} \text{ GeV}^{-1}$, $g_{aPP} < 10^{-7} \text{ GeV}^{-1}$ and $g_{aee} < 10^{-6} \text{ GeV}^{-1}$, respectively. These limits improve upon previous laboratory constraints for neutron and proton couplings by up to three orders of magnitude.

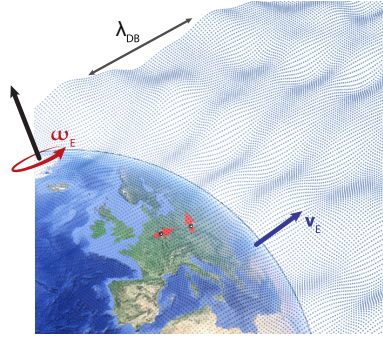


Fig. 1: Schematics of the comagnetometric interferometer. The two devices comprising the interferometer are indicated in their respective locations in Mainz and Kraków. The small red arrows at the Earth surface point in the directions of the sensor sensitivity axes. In our model, Earth is moving in the galactic rest frame at velocity v_E through the ALP DM field, characterized by its de Broglie wavelength λ_{DB} , that is more than a thousand times larger than the Earth radius. Besides its translational motion, Earth rotates around its axis giving rise to sidereal modulation of the signal at the frequency ω_E .

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The Role of Quantum Measurements in Experimental Tests of Quantum Gravity

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Testing the quantum nature of gravity in laboratory settings has recently become a rapidly developing field of research. In this context, we explore whether a *classical* theory of gravity can be constructed to describe gravitational interactions between quantum systems, while still reproducing all experimental results obtained so far. Such classical theories serve not only as “straw-man” models that can be experimentally ruled out, but also as valuable intermediate targets: excluding them generally requires less stringent experimental conditions than testing fully quantum theories of gravity. The central challenge in formulating a classical theory of gravity coupled to quantum systems lies in determining how *classical information* can be extracted from a quantum system to act as a source term in the gravitational field equations. Several candidate mechanisms for extracting such information have been proposed:

- (i) Taking expectation values of quantum operators;
- (ii) Performing continuous quantum measurements using a sequence of ancilla systems coupled to the system;
- (iii) Using information obtained directly from measurement outcomes accessible to the experimentalist.

Historically, mechanism (i) has been employed in the Schrödinger–Newton (SN) theory [1], which introduces a nonlinear modification to the Schrödinger equation. However, nonlinearities can lead to causality violations once quantum measurement is taken into account. We have shown that this issue can be resolved by reformulating the SN theory using mechanism (iii), i.e., by taking expectation values over the *conditional* quantum state obtained from actual measurement outcomes. This leads to what we call the *Causal-Conditional Schrödinger–Newton* (CCSN) theory [2,3,4,5], which restores causality while retaining the classical character of gravity.

Notably, ancilla systems used in (ii) are conceptually similar to those invoked in objective collapse models, such as the Continuous Spontaneous Localization (CSL) and Diósi–Penrose theories [6], which postulate that quantum states spontaneously collapse and prevents macroscopic superpositions. If the information recorded in these ancilla systems is used to generate classical gravitational fields, one recovers models of the type proposed by Nimmrichter and Hornberger [7]. A more comprehensive theoretical framework for such interactions has been developed by Oppenheim [8].

We emphasize, however, the key role played by measurement results *obtained by the experimentalist*, i.e., mechanism (iii) [9]. The persistent lack of experimental evidence for objective collapse suggests that, if such collapses occur at all, they primarily affect the states of measuring devices rather than the quantum systems so far constructed. In this light, it is natural to posit that classical gravity must be sourced primarily by classical information available to the observer. This perspective reinforces the CCSN framework as a promising candidate for describing classical gravity sourced by quantum matter. For completeness, however, one should also consider hybrid models in which both (ii) and (iii) contribute to sourcing the classical field.

We have also applied the SN theory to analyze possible experimental implications. While examining steady-state entanglement generation via Newtonian gravitational interactions, we found that even in a classical-gravity setting, certain choices of steady-state measurements could produce *apparent* entanglement, since these choices can be causally communicated between observers. Therefore, only *loophole-free* protocols — typically involving non-steady-state, dynamically varying measurements — can unambiguously distinguish quantum gravity from classical models.

Finally, we investigated gravitational self-interaction within the SN framework. For macroscopic objects, self-gravity can lead to significantly stronger experimental signatures than mutual-gravity experiments. This is because the mass of a solid object is concentrated near its lattice sites, leading to a local mass density much greater than the object’s average density. Such microscopic inhomogeneities enhance self-gravitational effects, potentially bringing them within reach of precision experiments in the nearer future.

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Optical metrology of atomic and molecular systems

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The energetic structure of atoms and molecules is determined by the interaction between their components and the surrounding space. Therefore atoms can be used to look for perturbation by dark matter fields [1]. On the other hand, molecules are especially attractive to test quantum electrodynamics (QED) [2] in systems more complex than a single atom and look for more exotic interactions like hadron-hadron fifth forces or short range non-Newtonian gravitation [3]. It was demonstrated that even a single optical atomic clock can be sensitive to coupling with a possible dark matter field [4] and the global network of such sensors was arranged [5]. Doppler limited cavity-ring down spectra of D₂ analysed with ab initio line shape profiles [6,7] provided an accurate experimental test [8] of QED calculations for this system [9]. A proof-of-principle demonstration [10] of use of photoassociation spectroscopy of weakly bound molecules was carried with ultracold Yb₂ for determination of constraints on fifth forces or non-Newtonian interactions between atoms. Prospects for farther improvement of discussed techniques can be seen in a pure frequency dispersion spectroscopy [11,12,13], development of optical molecular clocks [14,15] and use of ultracold systems involving Hg atoms [16]. Moreover, new areas of investigations are opened by laser cooling of positronium [17,18].

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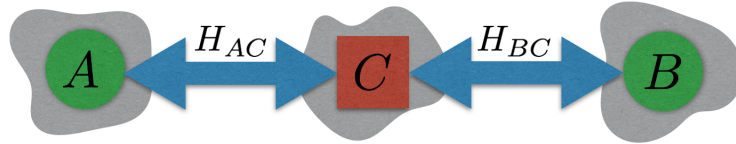
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Non-classical mediators and gravitational entanglement

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We investigate generic tripartite quantum systems where two controllable probe systems, A and B , interact via an inaccessible mediator, C , as in the figure below. A key question is how to detect non-classical properties of the mediator and its interactions without direct access to it.



It has been shown that entanglement gain between the probes serves as a witness of non-classical correlations with the mediator, independently of its Hilbert space dimension, interaction Hamiltonians, initial state, or exposure to local environments [1]. Furthermore, substantial increment in quantum correlations between the probes — whether entanglement or other quantifiers monotonic under local operations — is possible only if the interaction Hamiltonians H_{AC} and H_{BC} do not commute [2,3]. We first present qualitative arguments assuming a finite-dimensional mediator and then extend our analysis to infinite-dimensional cases [3].

A significant application of these methods lies in probing the non-classical nature of gravity and its interaction with quantum matter. We will summarise various notions of non-classicality that have occurred in the literature, see e.g. [4-7], and will analyse the precise extent to which gravity can entangle two quantum masses. Notably, the force gradient plays a pivotal role in gravitational entanglement generation [8]. Beyond entanglement, state swapping via gravity is also interesting to be observed as it requires non-commuting particle-field couplings [3]. Recent arguments show that gravity can indeed facilitate such a swap [9].

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Exploring quantum computing frontier with programmable neutral atom systems

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We will discuss recent advances in realizing programmable quantum systems using neutral atom arrays excited into Rydberg states. These systems allow control over several hundred qubits in two dimensions and the exploration of quantum algorithms with encoded logical qubits and quantum error correction techniques. Recent experiments using neutral atom systems have redefined this exciting scientific frontier of quantum computing. They herald the advent of early error-corrected quantum computation and chart a path towards large-scale logical processors. Examples of emerging scientific directions, in areas ranging from architectural mechanisms for universal fault tolerant quantum processing and many-body physics to quantum chemistry and quantum gravity will be discussed.

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Large Scale Quantum Optical Neural Networks in a Phase-Space Framework

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Quantum optical neural networks offer new perspectives for information processing beyond classical limits. However, previous theoretical studies of bosonic optical quantum neural networks have been limited to small-scale systems due to the exponential growth of the Hilbert space required for accurate simulations. This limitation has significantly constrained prior research, leaving the behavior of multi-mode bosonic reservoirs largely unexplored. During this talk, we demonstrate how the phase-space positive- $\mathcal{P}$ (PPM) method [1] can overcome these challenges by providing a robust and scalable computational framework capable of simulating large-scale bosonic neuromorphic systems with dozens of nodes. We focus on applying PPM within the quantum reservoir computing framework—a modern approach to quantum information processing [2] inspired by artificial neural networks. Our results show that bosonic quantum reservoir neural networks can successfully perform tasks such as quantum state classification (see Fig.1) and feature prediction. Crucially, we find that the performance of large quantum reservoirs does not increase monotonically with the number of bosonic modes. Instead, a complex dependence emerges, influenced by system nonlinearity, reservoir size, and input mode occupation. We identify a key limitation of large-scale quantum reservoir computing, where distributing input quantum information over too many reservoir nodes reduces the accuracy of quantum machine learning tasks. Therefore, we introduce a structured reservoir design and targeted optical injection to address this challenge, demonstrating how tailored configurations can mitigate performance degradation in large-scale systems. These results provide a solid theoretical foundation for scalable quantum-optic neuromorphic computing.

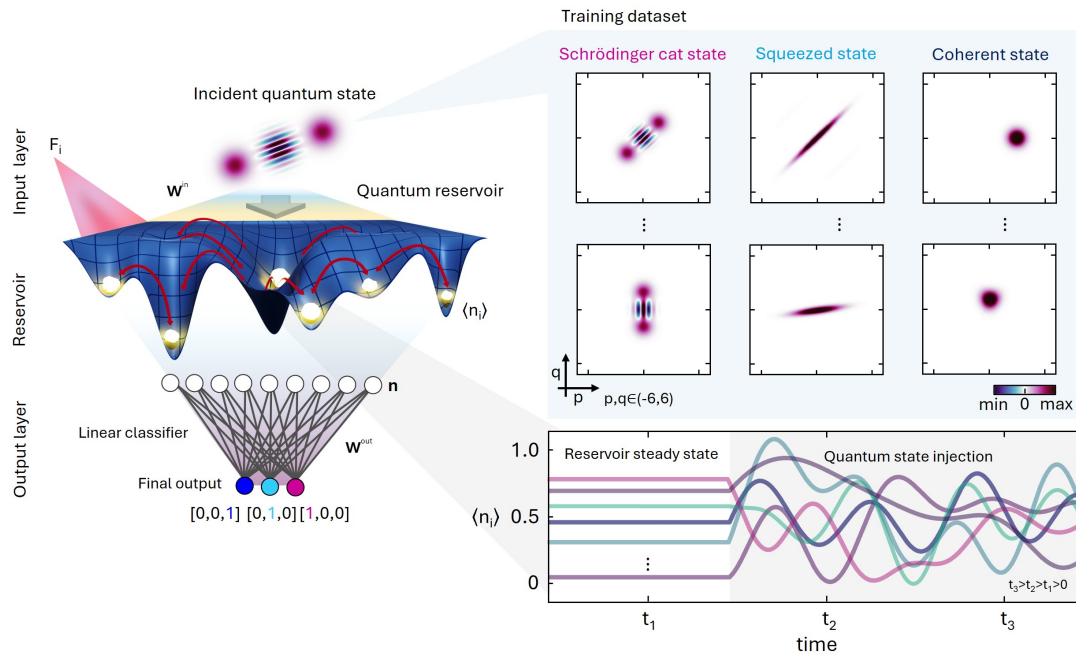


Fig. 1: Schematic illustration of a bosonic reservoir for quantum state recognition.

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Cavity-enhanced atomic magnetometer for micro-bio-magnetic measurements

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In optically pumped magnetometers (OPMs), an optical probe detects coherent precession of an atomic ensemble due to a magnetic field. Commonly employed optical probes employ optical polarization rotation or optical absorption. Here we study a probe based on optical phase shifts. As a step toward optically pumped magnetometers with sub-mm spatial resolution, we demonstrate continuous Pound-Drever-Hall (PDH) nondestructive monitoring of the electron spin polarization of an atomic vapor in a microfabricated vapor cell within an optical planar resonator by measuring the resulting line shift of a circularly polarized cavity mode [1]. The method appears well-suited to improving the effective optical path in micro-fabricated atomic vapor cells, analogous to what has been done with multi-pass geometries in macroscopic cells. The signal enhancement will be proportional to the cavity finesse, that in our case, $\mathcal{F} \approx 18$ (for a blue detuning of $2\pi \times 115$ GHz).

In this work, we apply this PDH technique to monitor Larmor precession by recording train of Free Induction Decay (FID) signals for magnetometry. We study the magnetometer performance, sensitivity and stability by showing the Allan deviation curve. Moreover, we describe the application of the OPM to study the ability of magnetotactic bacteria (MSR-1) to orient in an external magnetic field, which along with their ability to migrate towards regions depleted in oxygen, make MTB potential candidates for cancer treatment [2]. The described technique allows the miniaturization of the atomic magnetometer while maintaining high optical depth and can work off-resonance and therefore, it could potentially enable spin squeezing via quantum non-demolition (QND) measurements [3], which can be used in the future to beat the atomic noise of the magnetometer.

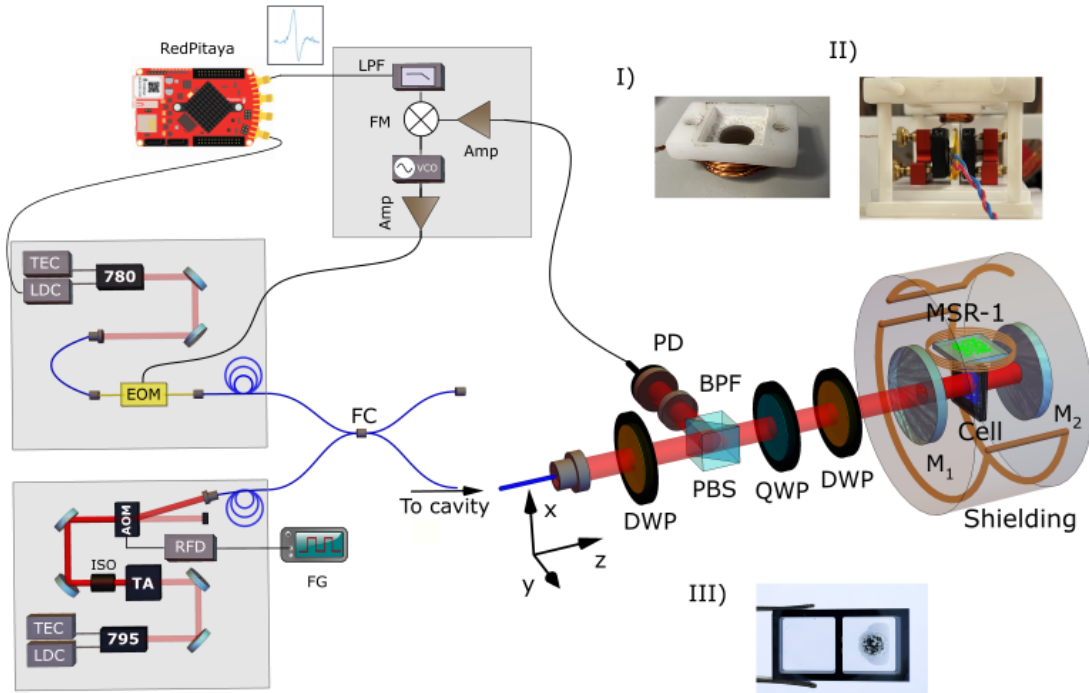


Fig. 1: Experimental setup for cavity-based detection of atomic polarization. I) Polarizing coils and bacteria solution. II) Cavity, cell and 3D printed structure. III) MEMS cell.

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Wednesday

09:00 am - 09:40 am	Anne L'Huillier Attosecond light pulses for studying electron dynamics
09:40 am - 10:20 am	Mordechai Segev Classical and quantum aspects of photonic time-crystals
10:20 am - 10:40 am	Krzysztof Sacha Time-tronics: from temporal printed circuit board to quantum computer
10:40 am - 11:00 am	Nadine Meyer Accelerated State Expansion of a Nanoparticle in a Dark Inverted Potential
11:00 am - 11:30 am	Coffee break
11:30 am - 12:10 pm	Mete Atatüre Taming Nuclear Spin Ensembles with Quantum Optics
12:10 pm - 12:50 pm	Monika Aidelsburger Quantum simulation – Engineering & understanding quantum systems atom-by-atom
12:50 pm - 01:10 pm	Gaia Stella Bolognini Microscopy of Density-Wave Ordering in Strongly Interacting Fermi Gases
01:10 pm - 02:40 pm	Lunch
03:00 pm - 05:30 pm	City tour
06:30 pm - 10:00 pm	Gala dinner



Wednesday

ATTOSECOND LIGHT PULSES FOR STUDYING ELECTRON DYNAMICS

Anne L'Huillier

Physics Department, Lund University

Extreme Ultraviolet light sources based on high-order harmonic generation in gases are now utilized in various scientific fields. The radiation consists of a train of extremely short light bursts, in the 100-attosecond range, allowing for outstanding temporal resolution.

Attosecond pulses enable the study of photoionization of atoms and molecules in a completely new way. Through the availability of a synchronized probe field and interferometric measurements, it is now possible to measure time delays in photoionization and the phase change of an electron wave packet across a Fano resonance. Recently, the use of a bicolour probe field has allowed us to perform quantum state tomography of a photoelectron.

Photonic Time-Crystals and Light-Matter Interactions therein

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Photonic Time Crystals (PTCs) are dielectric media whose refractive index is strongly modulated periodically in time at time scales of a single optical cycle. These systems conserve momentum but not energy, and are characterized by momentum bands and bandgaps where the amplitudes of their eigenmodes can increase or decrease exponentially [1,2].

The fundamentals of PTCs will be introduced along with the classical and quantum features of light-matter interactions in PTCs. Among these, the most notable is the emission of light in PTCs [3,4], which opens new avenues for making widely tuneable lasers that do not rely on any atomic resonance and draw their energy from the temporal modulation of the medium. Another important feature is the quantum aspects, which yield a plethora of fundamental features ranging from the generation of pairs of entangled photons by the modulation [3,4], the ability to control spontaneous emission through the temporal modulation [5], and the suggestion to create 2D cluster states [6].

Finally, recent experimental progress on time-refraction in the regime of a single optical cycle [7] will be presented, focusing on the progress towards time-reflection at optical frequencies. Last but not least, nonlinear optics in such time-varying media will be discussed, envisioning new mechanism for high harmonic generation in solids that can yield large photon flux.

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Time-tronics: from temporal printed circuit board to quantum computer

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Time crystalline structures can be created in periodically driven systems. They are temporal lattices which can reveal different condensed matter behaviours ranging from Anderson localization in time to temporal analogues of many-body localization or topological insulators. However, the potential practical applications of time crystalline structures have yet to be explored. **We pave the way for time-tronics where temporal lattices are like printed circuit boards for realization of a broad range of quantum devices.** The elements of these devices can correspond to structures of dimensions higher than three and can be arbitrarily connected and reconfigured at any moment. Moreover, **our approach allows for the construction of a quantum computer, enabling quantum gate operations for all possible pairs of qubits.** This research indicates that the limitations faced in building devices using conventional spatial crystals can be overcome by adopting crystalline structures in time.

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Accelerated State Expansion of a Nanoparticle in a Dark Inverted Potential

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Levitated nanoparticles provide a powerful and flexible platform for quantum optomechanics, offering exceptional isolation from the environment and a simple, well-defined mode structure. Unlike clamped mechanical resonators, the absence of physical supports allows for in situ tuning of the potential landscape without the need for complex nanofabrication. This level of control makes levitated systems particularly attractive for exploring macroscopic quantum phenomena, as well as for applications in force and inertial sensing. A key challenge in generating large quantum superposition states of massive objects is the efficient expansion of their wave packets. While free evolution leads to linear growth of the position uncertainty, an inverted harmonic potential enables exponential expansion, offering a pathway to rapidly amplify quantum fluctuations to macroscopic scales. In this work, we demonstrate this principle experimentally by expanding the center-of-mass thermal state of a 125 nm silica nanoparticle to a position uncertainty of 43.4 nm in just 260 μ s. By employing an inverted dark optical potential, we suppress heating mechanisms from photon recoil, achieving a 952-fold increase in spatial uncertainty—approaching the physical size of the particle itself. This classical state expansion represents a significant step toward realizing macroscopic quantum superpositions at previously inaccessible mass and length scales.

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Taming Nuclear Spin Ensembles with Quantum Optics

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Optically active spins in solids are strong candidates for scalable devices towards quantum networks. Semiconductor quantum dots set the state-of-the-art as single-photon sources with high level tuneability, brightness, and indistinguishability. In parallel, their inherently mesoscopic nature leads to a unique realisation of a tripartite interface between light as information carrier, an electron spin as a proxy qubit, and an isolated nuclear spin ensemble. The ability to control these constituents and their mutual interactions create opportunities to realize an optically controllable ensemble of $\sim 50,000$ spins. In this talk, I will present a journey from treating the quantum dot nuclei as an uncontrolled noise source limiting spin coherence to the observation of their collective magnon modes and eventually to their function as a quantum register, all witnessed via a single electron spin driven by light.

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Quantum simulation – Engineering & understanding quantum systems atom-by-atom

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The computational resources required to describe the full state of a quantum many-body system scale exponentially with the number of constituents. This severely limits our ability to explore and understand the fascinating phenomena of quantum systems using classical algorithms. Quantum simulation offers a potential route to overcome these limitations. The idea is to build a well-controlled quantum system in the lab, which represents the problem of interest and whose properties can be studied by performing controlled measurements.

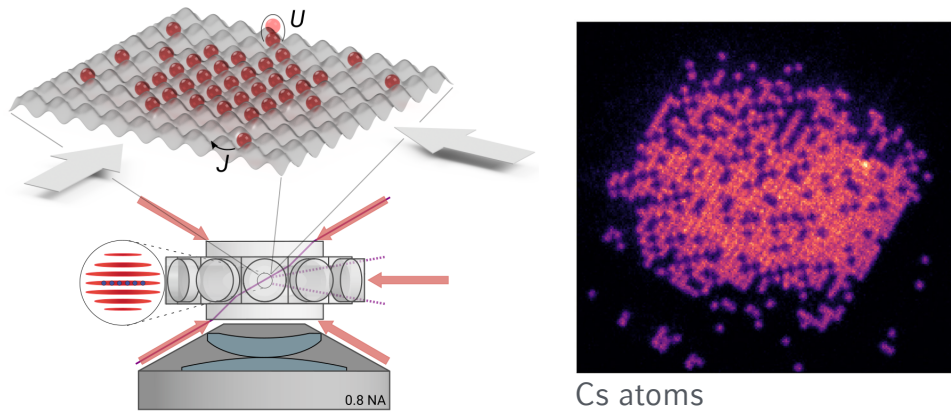


Fig. 1: Left: Schematic of the quantum gas microscope setup with a high-NA imaging objective. Atoms are confined in a square optical lattice and a single vertical plane. Right: Fluorescence image of Cs atoms.

Quantum simulators based on neutral atoms in optical lattices offer access to ultra-low temperatures and long coherence times. Recent advances pave the way towards high-fidelity simulations using arrays of several thousand atoms with single-atom resolution and control in homogeneous lattice potentials, where the atoms are confined in a box. In this talk, I will demonstrate how such systems enable the exploration of interacting topological phases of matter using Floquet engineering [1] and provide insights into fundamental questions regarding the thermalization of isolated quantum systems in the regime of Hilbert-space fragmentation [2]. In addition, I will highlight recent advances facilitated by the programmability of these platforms enabling access to arbitrary orbital operators [3], such as current and kinetic energy, beyond conventional density or occupation measurements. Moreover, by analyzing subsystem return probabilities we reveal the relevance of genuine higher-order connected correlation functions for the observed dynamical quantum phase transition and conduct a quantitative measurement of the size of the accessible Hilbert space in the thermodynamic limit [2]. Finally, I will conclude by providing an outlook towards new capabilities by combining direct ground-state cooling in optical lattices with local control provided by tweezer arrays [4].

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Microscopy of Density-Wave Ordering in Strongly Interacting Fermi Gases

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Analog quantum simulations using ultracold atoms offer exciting opportunities to investigate many-body systems in highly controllable and tunable settings. While most studies have focused on simulation of systems with short-range interactions, their interplay with long-range interactions remains largely unexplored.

In our experimental platform, the atomic ensemble is strongly-coupled to a high finesse optical resonator, whose photons mediate an effective all-to-all and long-range interaction among the particles [1, 2]. Upon reaching a critical long-range interaction strength, the system undergoes a phase transition into a density wave ordered state, characterized by the superradiant build up of the cavity field and the atomic self-organisation into a crystalline lattice [3]. While this phenomenon has been extensively studied in bosonic quantum gases [4, 5], we explore the effect of this transition in a degenerate two-component Fermi gas of ^6Li with tunable short-range interactions.

I will present our recent experimental results on probing this phase transition using not only the detection of the leakage of the cavity field but also high-resolution microscopy over the atomic cloud. In particular, we present the first direct, in-situ imaging of the periodic modulation of the charge density waves. Importantly, the photonic and the atomic signatures are independently recorded from the same quantum trajectory of the hybrid system in a single shot, revealing the correlation between the intra-cavity field and the spatial ordering of the atoms.

The capability to probe the atomic cloud at the micrometer scale opens interesting avenues for investigating the ordering process, enabling the extraction of in-situ quantities that cannot be accessed through the cavity-field detection alone, such as direct observation of spatial correlations. Additionally, we anticipate the use of the microscope for precise control and manipulation of the atomic trapping potential, unlocking new opportunities for the exploration of fermionic systems in long range interaction induced phase transitions.

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Thursday

09:00 am - 09:40 am	Alexander Streltsov Catalysis of quantum entanglement and entangled batteries
09:40 am - 10:20 am	Piet O. Schmidt Quantum engineering optical clocks based on trapped ions
10:20 am - 10:40 am	Michał Matuszewski Engineering quantum many-body interactions with strong light-matter coupling
10:40 am - 11:00 am	Piotr Grochowski Optimal control of mechanical systems in the quantum regime
11:00 am - 11:30 am	Coffee break
11:30 am - 12:10 pm	Ana Maria Rey New directions in quantum simulation using long-lived dipoles in an optical cavity
12:10 pm - 12:50 pm	Dan Stamper-Kurn Optically driven atom arrays and new resources for ultracold atomic physics
12:50 pm - 01:10 pm	Michał Szurek Super and Sub-Radiance in a Tunable Spacing Quantum Gas Microscope
01:10 pm - 02:40 pm	Lunch
02:40 pm - 03:20 pm	Philipp Hauke Quantum simulation of holographic quantum matter and gauge theories
03:20 pm - 03:40 pm	Jan Kolodynski Quantum sensors operated in real time: from Bayesian inference to machine learning
03:40 pm - 04:00 pm	Aleksandra Sierant Quantum enhancement in a multi-parameter quantum sensor
04:00 pm - 04:20 pm	Stanisław Kurczyna Quantum error mitigation with long-lived collective Rydberg excitations
04:20 pm - 04:50 pm	Coffee break
04:50 pm - 05:10 pm	Tomasz Wasak Engineering interactions by collective coupling of atom pairs to cavity photons for entanglement generation
05:10 pm - 05:30 pm	Pau Farrera Heralded generation of atom-photon entanglement
05:30 pm - 05:50 pm	Bartosz Niewelt Long-lived collective Rydberg excitations in atomic gas achieved via ac-Stark lattice modulation
05:50 pm - 06:10 pm	Perola Milman Quantum information in quantum optics from a superselection rule compliant perspective
06:30 pm - 08:00 pm	Poster session



Poster Sessions

Bertran Soria Pastor	Thu – 2	Saravanan Sengottuvel	Thu – 27
Donika Imeri	Thu – 3	Patrycja Tulewicz	Thu – 28
Bartosz Kasza	Thu – 4	Mariusz Semczuk	Thu – 29
Mateusz Salamon	Thu – 5	Christopher Kiehl	Thu – 30
Èlia Solé Cardona	Thu – 6	Tanausú Hernández Yanes	Thu – 31
Abhishek Ghosh	Thu – 7	Adrien Poindron	Thu – 32
Jorge Mellado-Muñoz	Thu – 8	Adam Koza	Thu – 33
Jacek Gębala	Thu – 9	Crislane De Brito	Thu – 34
Ivana Puljić	Thu – 10	Santiago Tabares	Thu – 35
Marcin Jastrzębski	Thu – 12	Marija Ćurčić	Thu – 36
Maciej Ogrodnik	Thu – 13	Zoran Grujić	Thu – 37
Karol Gietka	Thu – 14	Michał Matulík	Thu – 38
Damian Włodzyński	Thu – 15	Arash Dezhang Fard	Thu – 39
Naman Jain	Thu – 16	Hamid Reza Hamed	Thu – 40
Michał Mikołajczyk	Thu – 17	Marek Kopciuch	Thu – 41
Grzegorz Chimczak	Thu – 18	Wenchao Xu	Thu – 42
Grzegorz Kowzan	Thu – 19	Ilango Maran	Thu – 43
Jan Wójcik	Thu – 20	Jayanth Jayakumar	Thu – 44
Matthew Frye	Thu – 21	Daniel Ortuño-Gonzalez	Thu – 45
Diana Mendez Avalos	Thu – 22	Emmanuel Klinger	Thu – 46
Zoi Sargianni	Thu – 23	Marek Tylutki	Thu – 47
Jerzy Szuniewicz	Thu – 24	Joanna Kalaga	Thu – 48
Maciej Bartłomiej Kruk	Thu – 25	Sylvia Kondej	Thu – 49
Anuradha Tonipe	Thu – 26		



Catalysis of quantum entanglement and entangled batteries

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Entanglement is a fundamental resource in quantum information science, yet its manipulation—especially under operational constraints—remains incompletely understood. This talk presents recent advances that bridge key conceptual gaps in our understanding of entanglement transformations, both in single-copy and asymptotic regimes, by introducing two powerful tools: entanglement catalysis and entangled batteries.

We begin by addressing the fundamental question of how to convert one entangled pure state into another in the single-copy regime, assisted by an auxiliary entangled state—a catalyst. We further allow the process to establish correlations between the main system and the catalyst, provided that these correlations can be made arbitrarily small. Remarkably, we show that the entanglement entropy precisely characterizes which such transformations are possible: a pure-state transformation can be performed if and only if it is entanglement-non-increasing [1]. The quantum catalysts, much like their chemical counterparts, facilitate transformations that are otherwise impossible, yet emerge completely unaltered at the end of the process. This result elevates entanglement entropy from a purely asymptotic quantity to a fully operational measure, governing state convertibility even in the most resource-constrained, single-shot scenarios.

In the second part, we explore the relationship between catalytic and asymptotic entanglement manipulation [2]. While catalysis extends what is possible at the single-copy level, we prove that it does not improve asymptotic singlet distillation rates for distillable states. Despite this limitation, we find a deep equivalence between the two regimes once correlations across many copies are accounted for. These findings clarify the boundaries of what catalysis can achieve and highlight the subtle role of correlations in asymptotic transformations of entangled states.

Finally, we turn to the question of reversibility in entanglement transformations. While irreversibility has been a central theme in mixed-state entanglement theory, we demonstrate that reversible transformations become possible under local operations and classical communication if parties have access to an entanglement battery—a quantum system that can store and supply entanglement without net loss [3]. This leads to a generalized second-law-like framework, where distinct entanglement quantifiers determine the rates of transformation. Our results establish a broad and flexible foundation for reversible entanglement manipulation and extend naturally to multipartite systems and other quantum resource theories.

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Quantum engineering optical clocks based on trapped ions

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Optical atomic clocks with eighteen significant digits are the most accurate measurement devices available to us with applications ranging from tests of fundamental physics to height difference measurements in relativistic geodesy [1]. The uncertainty in trapped-ion clocks is limited by systematic frequency shifts and quantum projection noise. In my presentation, I will show how quantum engineering techniques can overcome these limitations. Quantum algorithms provide access to new clock species such as highly charged ions with reduced systematic shifts and high sensitivity to searches for new physics [2], including hypothetical fifth forces [3], variation of fundamental constants and dark matter candidates. Dynamical decoupling [4] and entangled state spectroscopy [5] in a multi-ion frequency reference offer suppression of systematic shifts, while improving the signal-to-noise ratio of the clock and thus the required averaging time to reach a certain resolution [6]. These developments will pave the way towards a next generation of quantum-enhanced clocks that enter the 10^{-19} relative frequency uncertainty regime.

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Engineering quantum many-body interactions with strong light-matter coupling

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Description of many-body light-matter interactions in the regime of strong-light matter coupling is usually presented within the framework of the seminal work of Hopfield, where the concept of polariton was introduced [1]. However, this description has several drawbacks that limit its applicability. The picture of several well-defined modes of light and matter modes interacting with each other is correct as long as the shapes of eigenmodes are not substantially modified by the interaction. Plane-wave description of polariton modes is far from reality in confined systems, while dissipative effects can lead to substantial corrections. This may lead to incompatibility of theoretical descriptions and physical realizations. To date, there is no systematic way to determine a quantum model in the form of a master equation, for a given physical nanostructure, that would take into account all its physical features.

We present a systematic method for obtaining precise form of quantum master equation from first principles, under the assumption of small size of emitters (such as excitons) compared to the wavelength of light, which are strongly coupled to light in a dielectric structure. The method is based on Bogoliubov transformation [2] in the conservative case and on the concept of third quantization [3] in the dissipative case. The procedure involves finding eigenmodes of Maxwell equations coupled to macroscopic polarization field in the classical limit, which can be performed by any solver of choice. We propose that this method can be used for engineering many-body nonlocal interactions between polariton modes in carefully designed structures. In one example, we design a semiconductor structure characterized by high nonlocality of interactions which leads to substantial quantum correlations between modes of emitted light (see Fig. 1).

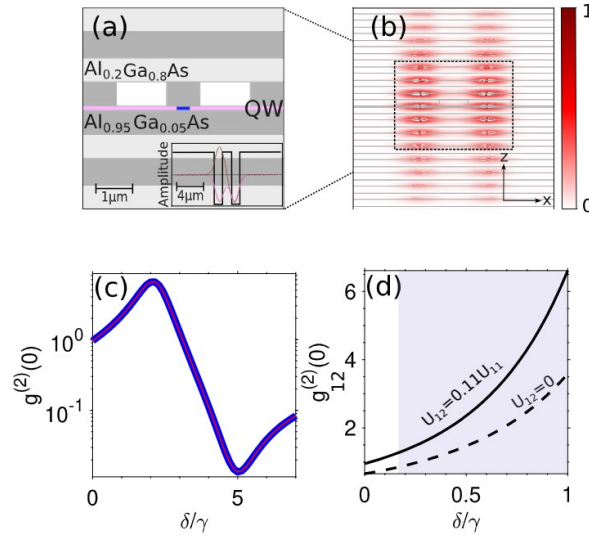


Fig. 1: (a) An example of an engineered semiconductor structure hosting exciton-polariton modes with nonlocal interactions. (b) Electric field intensity in the symmetric eigenmode. (c) second-order correlation function of emitted light in function of detuning. (d) cross-correlation showing enhancement of cross-mode correlations due to nonlocal interactions.

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Optimal control of mechanical systems in the quantum regime

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Contrary to the qubit-based, discrete systems, continuous quantum platforms enable encoding increased complexity into fewer physical systems through large-scale non-Gaussian states. Motion, as an exemplary continuous degree of freedom, underpins numerous nonlinear phenomena—from Cooper pair dynamics and optical wave packets to the macroscopic levitated objects. Despite significant progress in harnessing mechanical nonlinearities and generating quantum non-Gaussian states in low-energy regimes, their full potential remains untapped. Achieving high-quality, high-energy, and spatially large quantum non-Gaussian states is essential for progress in quantum sensing, quantum simulations, and foundational tests of quantum mechanics.

We explore the following control schemes for mechanical degrees of freedom in nonlinear systems, including atoms or particles trapped in nonharmonic potentials or clamped solid-state oscillators with available spin-motion coupling. **(i) Nonharmonic potential modulation.** First, we present a theoretical proposal for preparing and manipulating a state of a single continuous-variable degree of freedom confined to a nonharmonic potential [1]. By utilizing optimally controlled modulation of the potential's position and depth, we demonstrate the generation of various non-Gaussian states, as well as the implementation of arbitrary unitaries within a selected two-level subspace [Fig. 1(a)]. **(ii) Macroscopic quantum states of levitated nanoparticles.** Second, we introduce a method for the rapid preparation of the center of mass of a levitated particle in a macroscopic quantum state—one that is delocalized over a length scale much larger than its zero-point motion and has no classical analog [2]. This state is prepared by letting the particle evolve in a static double-well potential after a sudden switchoff of the harmonic trap, following initial center-of-mass cooling to a sufficiently pure quantum state [Fig. 1(c)]. **(iii) Phase-insensitive force sensing.** Finally, we consider a force-sensing scheme where the induced phase-space displacement direction is randomized and an excitation number resolving measurement is performed [3]. By applying quantum optimal control in a spin-boson system, we identify number-squeezed cat states as the optimal choice for maximizing force sensitivity under lossy dynamics and the finite system controllability [Fig. 1(b)].

These studies highlight different approaches to motion control—either leveraging intrinsic nonharmonicity in the confining potential or coherent coupling to an external nonlinear system. Our results provide a versatile control toolbox for nonlinear continuous-variable quantum systems, including scenarios with weak intrinsic nonharmonicity or limited external coherent coupling. As new mechanical platforms, such as levitated nanoparticles and bulk wave resonators, continue to advance into the quantum regime, developing robust control strategies for their motion becomes crucial for both fundamental physics and technological applications. Our work paves the way toward universal control of a broad class of continuous quantum systems, encompassing both massive mechanical oscillators and massless quantum fields such as optical and microwave resonators.

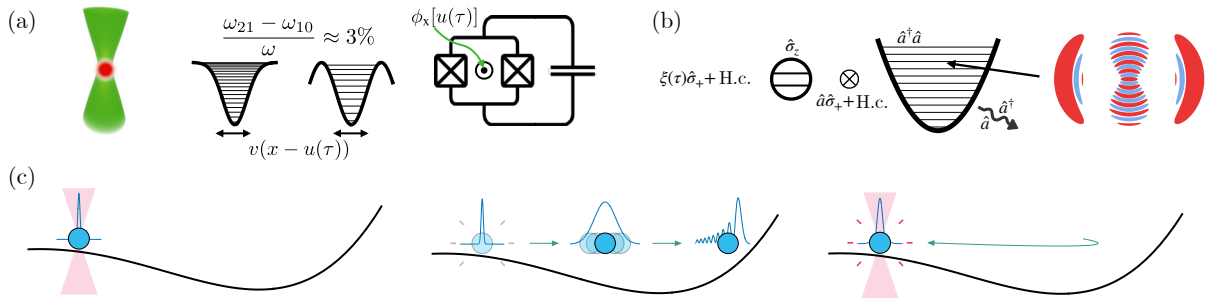


Fig. 1: (a) Examples of continuous nonlinear systems that can be optimally controlled without the need of auxiliary systems—single atoms in optical tweezers and flux-tunable transmons. (b) In an optimally controlled spin-boson model with finite controllability and decoherence, a family of number-squeezed cat states maximizes achievable sensitivity for weak force sensing. (c) Schematic representation of the protocol for the preparation of a macroscopic quantum state of a nanoparticle utilizing hybrid potential.

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New frontiers in quantum simulation and sensing via cavity mediated interactions

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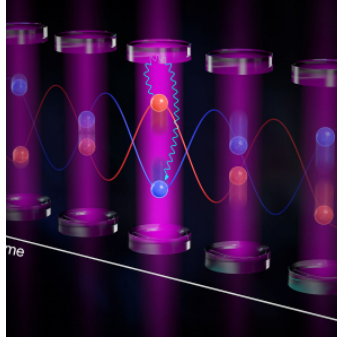


Fig. 1: Atoms in optical cavities are a unique platform for advancing quantum simulation and sensing.

Atoms and photons are the fundamental building blocks of our universe. Their interactions rule the behavior of our physical world but at the same time can be extremely complex, especially in the context of many-body quantum systems. Understanding and harnessing them is one of the major challenges of modern quantum science. In recent years, ultracold atomic systems have emerged as a pristine platform for the exploration of atom-light interactions. In this talk, I will discuss the potential of atomic systems loaded in optical cavities as a resource to enhance the energy scales needed to observe complex many-body behaviors by harnessing infinity range interactions mediated by photons that can couple a large set of internal levels. I will show how cavity systems can help us not only to shed light on behaviors of iconic Hamiltonians describing real materials but also to engineer broader classes of Hamiltonians with multi-body interactions too complex to emerge naturally. Furthermore, I will explain how they can facilitate the generation of quantum entanglement and overcome physical constraints currently limiting the performance of state-of-the-art atomic clocks and interferometers.

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Optically driven atom arrays and new resources for ultracold atomic physics

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New techniques and resources in ultracold atomic physics have continually deepened its impact on science. I will discuss two experimental developments that, hopefully, exemplify this trend. First, I will share how my research group is using the versatile tool of atom-tweezer arrays to study collective atom-light coupling and symmetry breaking in the mesoscopic regime. Specifically, we show how, akin to the response of metamaterials, the precise control over the positions of atoms affects their collective coupling to an optical cavity. This collective coupling to light affects the mechanical state of the tweezer-trapped atoms, leading to a phase transition between unbroken and broken symmetry states. This self-organization phase transition, akin to that predicted by the Dicke model, has been studied previously in macroscopic systems. Here, we examine such critical behavior in the mesoscopic regime and identify signatures of the enhanced fluctuations that are the hallmark of mesoscopic physics. Second, I will describe our efforts to bring new atomic elements into the ultracold regime, focusing on transition-metal atoms and specifically on titanium, which we have now succeeded in laser-cooling and trapping for the first time.

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Super and Sub-Radiance in a Tunable Spacing Quantum Gas Microscope

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Quantum gas microscopy permits the study of cooperative optical effects in a regime qualitatively distinct from what is traditionally realized in optical cavities and bulk gases. Here we explore super and sub-radiance beyond the Dicke limit via a tunable-spacing quantum gas microscope of erbium atoms. Our tightly spaced 266nm optical lattice, along with erbium's narrow 841nm transition, results in a favorable spacing-to-wavelength ratio for observing collective emission. We measure super and sub-radiance by tracking the excited state population of atoms undergoing decay and observe that super-radiance scales with system size in systems much larger than the light's native 841nm length scale. Sweeping the spacing-to-wavelength ratio reveals geometric resonances that result in revivals of super-radiance. Our microscope's single-site resolution reveals ferromagnetic spatial correlations through super-radiant emission and antiferromagnetic correlations in deeply sub-radiant regimes. Unlike in all-to-all interacting systems that are restricted to the Dicke manifold, our system moves throughout the angular momentum manifold as it decays. We measure the magnetization in our experiment to track the dynamics of this decay and map out the trajectory of finite-inversion preparations through the Hilbert space. This work paves the way for future work in studying cooperative effects in ordered atomic arrays with applications in engineering photonic states for quantum communication and dissipative generation of exotic quantum states.

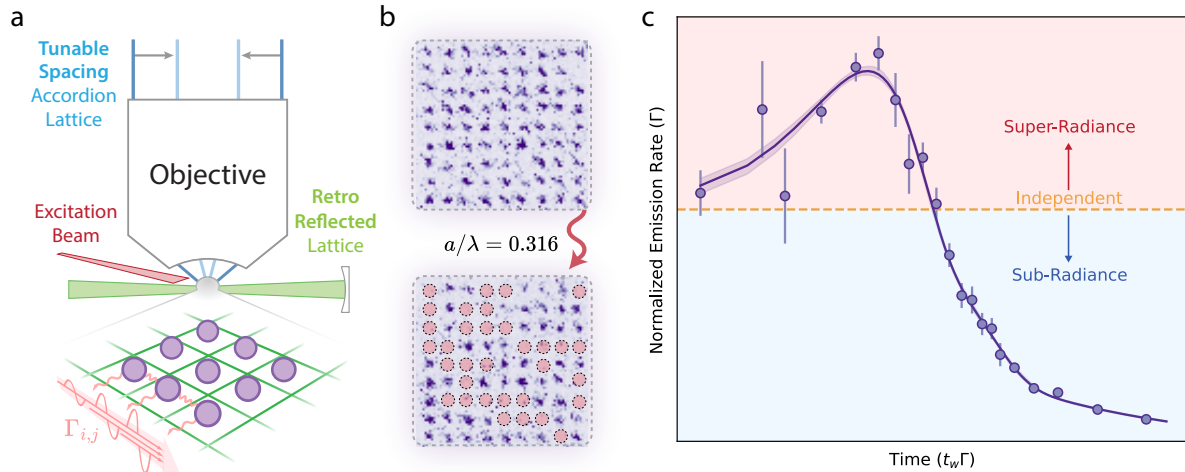


Fig. 1: **a.** Retro-reflected 532nm light forms an optical lattice with 266nm spacing between atoms. 488nm light projected through a high numerical aperture objective forms a tunable-spacing "accordion lattice". Atoms loaded into lattice are transferred to the excited state of the 841nm transition via an excitation beam incident to the side of the atom plane. Here $\Gamma_{i,j}$ indicates distance-dependent cooperative emission that is otherwise distance-independent in the Dicke limit. **b.** Excited state population throughout collective emission is measured via single-site fluorescence imaging. The short interatomic spacing to transition wavelength ratio ($a/\lambda = 0.316$) parametrizes a favorable regime for cooperative effects. **c.** Measured emission rate over time for a system of 1000 atoms. The orange dashed line corresponds to the decay rate of independent, non-interacting atoms.

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Quantum simulation of holographic quantum matter

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Holographic quantum matter—i.e., field theories that are dual to bulk gravity—represent paradigms for non-Fermi-liquid behavior and for extreme quantum chaos, cementing a deep interest throughout communities ranging from quantum gravity, over quantum information, to condensed matter. Yet, existing laboratory implementations in quantum simulators have been able to tackle only relatively small systems.

In this talk, I will present our ongoing efforts towards scalably realizing the Sachdev-Ye-Kitaev model, a paradigm for holographic quantum matter, by analog quantum simulation in cavity QED setups [1,2,3]. I will discuss first experimental steps done by the group of Jean-Philippe Brantut, EPF Lausanne, the realization of a disordered spin system showing grey polaritons and finite-size disorder transitions [4]. I will also discuss a universal equilibration dynamics that could represent a first experimental signature of the extreme chaos of such systems [5], how deformations such as algebraic power-law interactions affect their behavior [6], and how non-stabilizerness and entanglement increase as one reaches the holographic and chaotic regime [7]. With this talk, I aim to illustrate the extreme richness of physics encountered in the quantum simulation of holographic models.

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Quantum sensors operated in real time: from Bayesian inference to machine learning

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From gravitational-wave detectors to cryogenically cooled microresonators, quantum effects have been shown to enhance capabilities of various devices in sensing external perturbations. Although this fact has led to important breakthroughs in the field of quantum metrology, one often forgets that the vast majority of real-life applications require quantum sensors to track signals that vary over time—e.g., gravitational waves generated by black holes merging, or fluctuating magnetic fields generated by the human brain. In my talk, I will summarise recent results obtained within my group, in which we combine the description of continuously monitored quantum sensors with methods of signal processing, so that quantum effects can still be used to boost the sensitivity in “real time”.

Firstly, I will focus on an *optomechanical sensor*, see Fig. 1(a), operated in the non-linear regime [1], in order to show how the non-classical correlations of photons being emitted may then enhance the sensitivity after resorting to Bayesian inference. For such a solution to be efficient, however, the computation of the likelihood (the probability of obtaining a particular photoclick pattern) must be circumvented [2]. As an alternative, I will present methods based on machine learning [3] that, despite relying on a model-free approach, can be made as accurate, as meaningful, and as effective. Secondly, I will consider the setting of an *optically pumped magnetometer* (OPM), Fig. 2(a). I will demonstrate that it is enough then to use methods of (Extended, Cubature) Kalman Filtering to track fluctuating and transient magnetic-field signals in real time [4], which in turn open doors to leveraging the interatomic entanglement, i.e. spin-squeezing [5]. Such quantum-enhancement can then be stabilised by employing measurement-based feedback [6], which allows one to track even magnetocardiography (MCG) signals under the relevant experimental conditions [7].

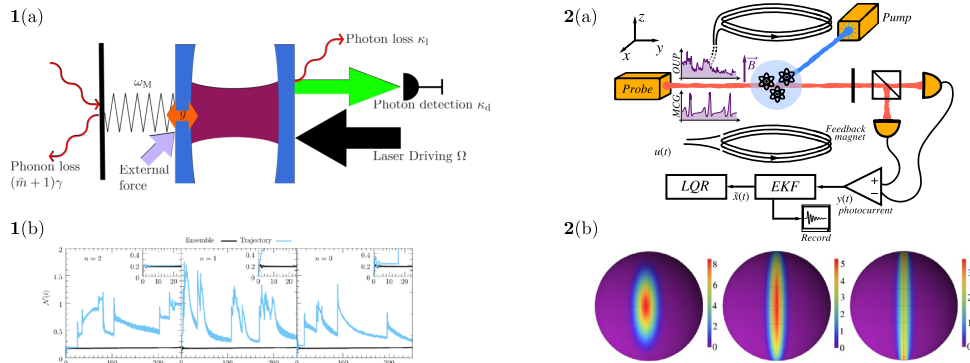


Figure: 1(a) – Canonical *optomechanical system* modelled as a cavity coupled to a mechanical device, with measurement corresponding to photodetection of photons leaking from the cavity; 1(b) – Negativity as a signature of entanglement between optical and mechanical d.o.f.s, whose character depends strongly on the value of detuning between the driving laser and the cavity. 2(a) – The atomic magnetometry setup considered to track fluctuating and fast-varying inputs, which involves measurement-based feedback. 2(b) – The entanglement in between the constituent atoms is induced by continuously measuring their total angular momentum, so that by inspecting the (spherical) Wigner function of the ensemble the phenomenon of spin-squeezing is observed.

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Quantum enhancement in a multi-parameter quantum sensor.

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We study quantum enhancement of sensitivity and bandwidth using squeezed light in a multi-parameter quantum sensor, the hybrid rf-dc optically pumped magnetometer (hOPM) [1]. Using a single-spin ensemble, the hOPM acquires both the dc field strength (scalar magnetometry) and resonantly detects one quadrature of the magnetic field at a programmed frequency (rf magnetometry). In contrast to scalar OPMs [2], the back-action evasion in the hOPM is incomplete, leading to a complex interplay between the three quantum noise sources in this system: photon shot noise, spin projection noise, and measurement back-action noise. We observe these interactions using squeezed light as a tool to control the distribution of optical quantum noise between polarization Stokes components, and the resulting effect on readout quantum noise and measurement back-action (see Fig. 1) [3].

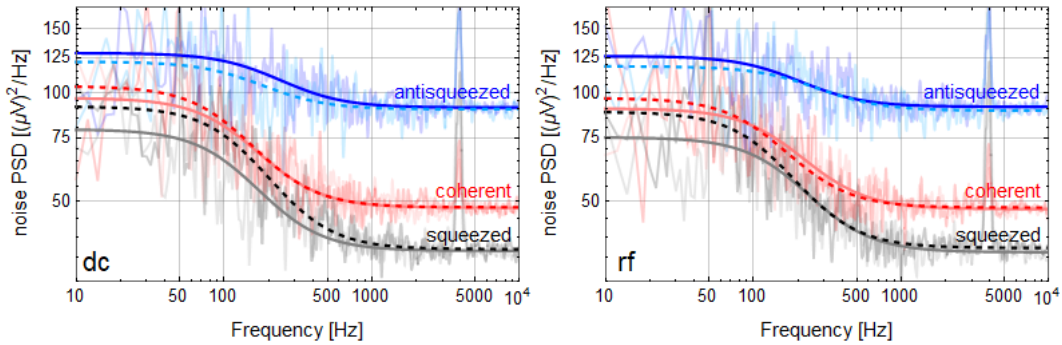


Fig. 1: Polarization noise after demodulation. Measured noise spectra along with the fitted model function, to compare the response bandwidth, the photon shot noise, and the low frequency atomic noise for coherent (red), squeezed (black) and anti-squeezed (blue) probing for polarized (dashed line) and unpolarized (solid line) atomic ensemble.

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Quantum error mitigation with long-lived collective Rydberg excitations

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Collective Rydberg excitations provide promising applications ranging from quantum information processing, and quantum computing to ultra-sensitive electrometry. However, their short lifetime is an immense obstacle in real-life scenarios. The state-of-the-art methods of prolonging the lifetime were only implemented for ground-state quantum memories and would require a redesign to effectively work on different atomic transitions. We propose a protocol for extending the Rydberg excitation lifetime, which in principle can freeze the spin-wave and completely cancel the effects of thermal dephasing. The protocol employs two coherence transfer beams that couple the ground part of the atomic coherence to an intermediate ground level. Our implementation showed that the excitation lifetime can be extended by an order of magnitude. Long-lived excitations are essential for interaction enhanced metrology scheme which allows for error mitigation in lossy experiments. With this protocol, we have achieved Fisher information per detected photon $\mathcal{F} = 3.3$, showing over threefold improvement as compared to standard procedure without additional losses before detection.

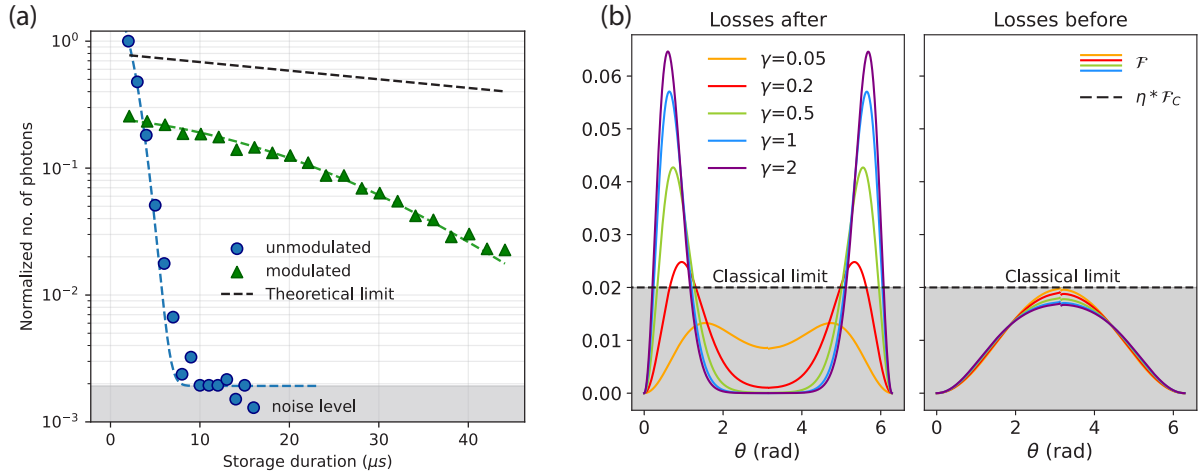


Fig. 1: (a) Rydberg memory lifetime for standard and modulated protocol. Blue dots represent the normalized intensity of unmodulated stored signal as a function of storage time. Green triangles represent the normalized intensity of stored signal modulated by shortening its spin-wave wavevector. The dashed grey line is the maximal possible theoretical limit of the modulation efficiency that takes into account imperfect polarizations due to rotation of beams. (b) Plot of Fisher information for different values of the parameter γ for losses $\eta = 0.02$ after the interaction. Fisher information at the beginning of the experiment without loss is $\mathcal{F}_C = 1$. In the case where losses are introduced after the interactions, there is an improvement in the Fisher information depending on the value of the decay constant γ .

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Engineering interactions by collective coupling of atom pairs to cavity photons for entanglement generation

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Engineering atom-atom interactions is essential both for controlling novel phases of matter and for efficient preparation of many-body entangled states, which are key resources in quantum communication, computation, and metrology. In our work [1], we propose a scheme to tailor these interactions by coupling driven atom pairs to optical cavity photons via a molecular state in the dispersive regime, resulting in an effective potential. Such a coupling has been recently demonstrated in [2, 3], where observation of universal pair-polaritons as well as the coupling of charge and pair-density waves were reported.

As an illustrative example of our approach, we investigate two-mode ultracold bosons in an optical cavity, see Fig. 1, and by analyzing the quantum Fisher information, we show that the induced interactions can generate robust many-body entanglement. By tuning the photon-induced interactions through the cavity drive, we identify conditions for preparing highly entangled states on timescales that mitigate decoherence due to photon loss. Our results show that the entanglement formation rate scales strongly with both photon and atom number, dramatically reducing the timescale compared to bare atomic interactions. We also identify an optimal measurement for exploiting the metrological potential of the atomic state in an interferometric protocol with significant photon losses, saturating the quantum Cramer-Rao lower bound. Furthermore, we show that despite these losses the atomic state exhibits strong Bell correlations. Our results provide insights on induced atom-atom interactions and open paths to study novel phases of light and matter in hybrid atom-photon systems, as well as for tailoring complex quantum states for new quantum technology protocols and fundamental tests of quantum mechanics.

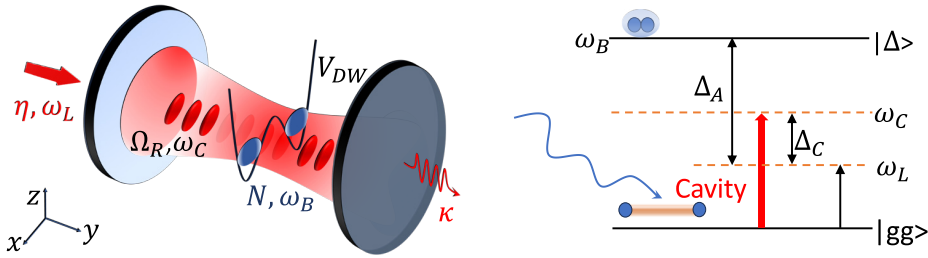


Fig. 1: **Left:** The scheme of the setup. N ultracold bosonic atoms are confined in a double-well potential V_{DW} inside an optical cavity. The laser pump η with frequency ω_L enters from one of the mirrors of the cavity with photon loss rate κ . Ω_R denotes the coupling of atom pairs with photons. **Right:** The diagram of the energy levels of atomic pairs gg and the molecule Δ . Δ_A and Δ_C are detunings from the molecular state and the cavity photon, respectively.

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Heralded generation of atom-photon entanglement

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One of the biggest current challenges in quantum information experiments and applications is reducing quantum state infidelity and inefficiency errors [1]. With reduced errors, quantum communication schemes can cover larger distances, and quantum computing algorithms can be faithfully implemented with larger circuit depths. In the context of quantum communication, one way to track and reduce inefficiency and infidelity errors is to herald the presence of the quantum state that is used as a resource [2,3]. While heralding photonic quantum states at their reception allows to track and reduce propagation and measurement errors, heralding the generation of such states at the source allows to immediately and faithfully react upon source errors.

Here we implement a new method to herald the successful generation of atom-photon entanglement. The method is based on the cascaded two-photon emission of a single atom into two crossed fiber cavities [4]. The polarization state of one photon is entangled with the spin degree of freedom of the atom, and the second photon heralds the successful entanglement generation. The polarization eigenmode splitting of the herald photon cavity is essential for steering a specific transition during the herald photon emission process, enhancing the fidelity of the entangled state.

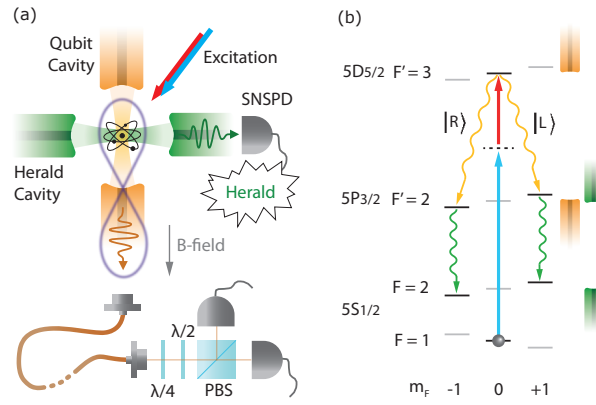


Fig. 1: (a) A single atom coupled to two crossed fiber cavities emits a photon entangled with the atom, and another photon that heralds the entangled state generation. (b) After exciting the atom to state $|5^2D_{5/2}, F=3, m_F=0\rangle$, a polarization qubit is generated in the qubit cavity, and the cavity-enhanced emission of a π polarized photon in the herald cavity brings the atom into a superposition of two spin states.

We show that the herald signal allows to track and reduce inefficiency and infidelity errors present during the entanglement generation process, improving the atom-photon entanglement efficiency and fidelity to 68(3)% and 86(2)%, respectively. We also use the temporal correlation information between the emission time of the qubit and herald photons in order to reduce photon qubit measurement noise. By obtaining a fidelity improvement from 48(3)% to 75(3)% in a noise-limited quantum communication situation, we highlight the potential of our heralded source for long distance quantum communication.

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Long-lived collective Rydberg excitations in atomic gas achieved via ac-Stark lattice modulation

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Collective Rydberg excitations have become an area of increasing interest across various important domains of physics. These excitations show great promise for applications in fields such as quantum information processing, quantum simulators, and ultra-sensitive electrometry [1]. However, their potential is constrained in practical situations by their short thermal dephasing time, which, at typical experimental temperatures of around 100 μK , is typically limited to no more than a microsecond. While some advanced techniques exist to extend the atomic coherence lifetime, they have only been applied to ground-state quantum memories. Applying these methods to Rydberg excitations would require substantial modifications to make them compatible.

We propose a novel approach based on Ac-Stark phase modulation of a quantum memory ensemble, which has the potential to freeze atomic coherence and completely suppress thermal decoherence effects. This protocol was implemented by interfering two off-resonant laser beams with the atomic medium, demonstrating that it is possible to achieve a ten-fold increase in lifetime [2]. To validate our findings, we simulated the evolution of atomic coherence in phase space, accounting for factors such as the finite duration of the modulation pulses, imperfect alignment of the experimental setup, and atomic motion across various velocity classes.

Our experimental results showed an improvement in lifetime by more than a factor of 10, approaching the natural lifetime of the Rydberg state limited by spontaneous and radiative dephasing. The proposed protocol enables measurements of Rydberg interactions over extended timescales, which is often essential for applications in electrometry or for utilizing long-lived collective qubits in quantum simulations and computational interfaces with light.

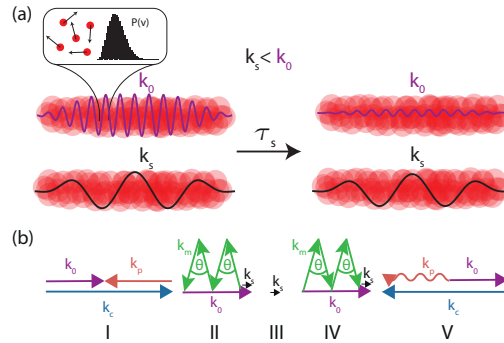


Fig. 1: (a) Blurring of the spinwaves with different wavevectors due to thermal motion of the ensemble. Spinwaves with larger wavevector are more affected by motional dephasing. (b) Geometrical representation of the stages of the extended lifetime protocol.

This research was funded in whole or in part by National Science Centre, Poland grant No. 2021/41/N/ST2/0311

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Quantum information in quantum optics from a superselection rule compliant perspective

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We present a general framework for representing quantum optical states that respects particle- number superselection rules, offering a consistent perspective on coherence, non-classicality, and their implications for quantum information. By adopting a two-mode Fock basis representation that explicitly incorporates the phase reference as a quantum resource, we describe quantum optical states using the same formalism as symmetric spin-like and angular momentum systems, and in a form that is invariant under $U(1)$ transformations [1]:

$$|\psi\rangle = \sum_{n=0}^N c_n |n\rangle_a |N-n\rangle_b. \quad (1)$$

The superselection rule compliant (SSRC) representation permits the representation of any state usually represented in quantum optics as coherent superpositions of Fock states. For example, states (1) are equivalent to states $\sum_{n=0}^{\infty} c_n |n\rangle_a$ in the usual representation, where a phase reference is implicitly assumed. The SSRC representation retains the intuitive appeal of traditional quadrature-based descriptions while providing a rigorous method for classifying quantum optical states as classical or non-classical based on their computational resource potential - that is mostly related to its non-separability properties in first quantization [2]. In addition, it enables a clear understanding of how multi-mode states and manipulations can potentially lead to quantum computational advantage - or to the impossibility of efficient classical simulation - of some quantum protocols.

Importantly, using the SSRC representation and applying physically motivated principles ($N \gg n_{\max} \gg \sum_{n=0}^{\infty} n |c_n|^2$), we can clearly identify the regime in which the continuous-variable (CV) representation of quantum optics captures the same phenomena as the more general framework we adopt here. In such a regime, it is possible to set $N \rightarrow \infty$ in (1).

Furthermore, the SSRC representation clarifies some seemingly contradictory results which appear when one implicitly assumes a phase reference. Using the representation (1) it is possible to define a SSRC universal gate set [2] based on mode rotations $e^{i\hat{J}_\pi\theta}$ (Gaussian quadrature operations), with $\hat{J}_z = \frac{1}{2}(\hat{a}^\dagger\hat{a} - \hat{b}^\dagger\hat{b})$, $\hat{J}_x = \frac{1}{2}(\hat{a}^\dagger\hat{b} + \hat{b}^\dagger\hat{a})$ and $\hat{J}_y = \frac{i}{2}(\hat{a}^\dagger\hat{b} - \hat{b}^\dagger\hat{a})$, and “spin-squeezing”-like operations $e^{i(\hat{J}_\pi)^2\eta}$, which are non-Gaussian quadrature operations. Using this universal set, it is possible to provide the underlying principles for accessing both the computational power and the non-classical properties of bosonic systems across all possible information encodings, from single-photon-based schemes to the CV limit, encompassing all possible error correction strategies in any physical platform [4]. In particular, our results permit identifying the necessary and sufficient conditions for universal quantum computing across any bosonic encoding, and show, for instance, that the only bosonic encoding where local quadrature non-Gaussian gates are not necessary is the single photons encoding. In addition, we show that qubit entanglement in any bosonic encoding is only possible with quadrature non-Gaussian gates.

Finally, from a purely physical perspective, by treating the phase reference explicitly as a resource, we also clarify the distinct roles of modes and states in quantum protocols and quantum optics more broadly, well separating the speakable and unspeakable properties of quantum optics [5].

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Friday

09:00 am - 09:40 am	Francesca Ferlino Magnetic Lanthanides: From Supersolidity to Multi-Electron Rydberg Physics
09:40 am - 10:00 am	Krzysztof Jachymski Quantum magnetism meets cavity QED
10:00 am - 10:20 am	Piotr Sierant Magic spreading in quantum many-body systems
10:20 am - 10:40 am	Tomas Lamich A single emitter emitting resonance fluorescence into a coherent probe beam
10:40 am - 11:00 am	Sankalp Sharma Beyond Single-Atom Coupling: Self-Organization through Cavity-Induced Atom-Pair Interactions in a Fermi Gas
11:00 am - 11:30 am	Coffee break
11:30 am - 11:50 am	Mykhailo Rakov Phase Diagram of the Disordered U(1) Quantum Link Model Created by Ultra-cold Alkaline-Earth-Like Atoms on a Two-Leg Ladder
11:30 am - 11:50 am	Maciej Gałka Realizing Integer and Fractional Quantum Hall states with a few rapidly rotating Fermions
12:50 pm - 01:00 pm	Closing
01:00 pm - 02:30 pm	Lunch



Magnetic Lanthanides: From Supersolidity to Multi-Electron Rydberg Physics

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The exploration of low-temperature physics has captivated scientists for decades, unveiling groundbreaking phenomena such as superfluidity across a variety of states of matter, including solids, liquids, gases, and even light. A central focus of this field has been the emergence of superfluid order in spatially homogeneous systems. However, what occurs when superfluidity emerges alongside periodic density modulations? Can a supersolid state exist, where localization inherent to periodic structures coexist with superfluidity? Is it possible for a solid to exhibit superfluid behavior, or for a superfluid to display crystalline order?

This talk will delve into the experimental realization of supersolidity in magnetic quantum gases, enabled by the momentum-dependent, long-range, and anisotropic dipole-dipole interactions. Key topics include the softening of roton excitations as a precursor to the supersolid phase transition and the observation of quantized vortices in rotating supersolid states.

Finally, I will review some recent advances on single erbium-atom in tweezers and Rydberg excitation.

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Quantum magnetism meets cavity QED

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The Dicke model is a central platform for exploring strong light-matter interaction and its superradiant properties, with implications for emerging quantum technologies. Recognizing that realistic qubits inherently experience direct interactions, we investigate the influence of both isotropic and anisotropic spin-spin couplings on the Dicke paradigm. In the strong coupling regime—where large photon populations challenge conventional numerical techniques—we developed a hybrid numerical method tailored for this problem, which demonstrates high accuracy and rapid convergence in reproducing established Dicke model results. This approach, based on a composite non-gaussian variational ansatz, can be applied to a multitude of systems from cavity QED to materials with strong electron-phonon coupling. For the case of the Dicke-Heisenberg model, our study reveals that distinct ferromagnetic and antiferromagnetic regions exhibit different orders of phase transitions. Most notably, in the presence of anisotropic interactions, we identify a novel phase where spin order and superradiance coexist, marked by enhanced superradiance with a photon number significantly exceeding that of the conventional Dicke model.

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Magic spreading in quantum many-body systems

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Quantum dynamics have captivated physicists for decades, in part due to the promise of quantum advantage—the potential for quantum devices to outperform classical computers. Entanglement is one of the resources necessary for quantum advantage. However, stabilizer states, despite exhibiting extensive entanglement, can still be efficiently simulated on classical computers. Quantum advantage, therefore, requires a system to possess also a significant degree of nonstabilizerness, also known as “magic,” a resource that quantifies how much a system’s state deviates from stabilizer states. How rapidly are magic resources generated by many-body dynamics under constraints of locality?

In this talk, I will address this question and discuss non-stabilizerness growth in quantum many-body systems. I will begin by describing the problem of magic spreading under the dynamics of brick-wall random unitary circuits [1], which combine principles of locality and unitarity, serving as a minimal model of ergodic many-body dynamics. For this model, a replica trick enables the investigation of non-stabilizerness dynamics on classical computers for systems comprising thousands of qubits. Our main finding is that magic resources equilibrate to their long time saturation values [2] already on timescales logarithmic in system size N , [1], differently from the entanglement entropy, see Fig. 1. Finally, I will discuss how the findings for random quantum circuits provide a reference point for studies of Floquet models and Hamiltonian systems [3].

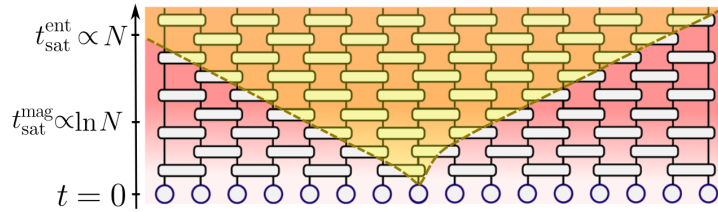


Fig. 1: Magic spreading in random quantum circuits which serve as minimal model of local many-body dynamics. A system of N qudits is prepared at time $t = 0$ in a product state $|\Psi_0\rangle$ with low-magic resources. Evolution under a quantum circuit comprising local Haar-random gates increases the nonstabilizerness of the state (denoted by the red gradient) and scrambles quantum information (symbolized by the light-cone). The nonstabilizerness approaches its long-time saturation value up to a given tolerance $\epsilon \ll 1$ at time $t_{\text{sat}}^{\text{mag}} \propto \ln N$, scaling logarithmically with system size N , while distant qudits become entangled only after a longer time $t_{\text{sat}}^{\text{ent}} \propto N$.

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A single emitter emitting resonance fluorescence into a coherent probe beam

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Resonance fluorescence from a single emitter is a paradigmatic quantum light source, in which a two-level system is coherently driven by laser light, and in response emits light that is anti-bunched, squeezed, and entangled. In 2021, Goncalves et al. [1] studied a variant of resonance fluorescence, in which the driven single emitter is placed in a probe beam containing a weak coherent state, a scenario that allows for both interference of laser light against resonance fluorescence, and stimulated emission by a single emitter.

We present an experimental implementation of the Goncalves et al. scheme, focussing on the exotic non-classical correlations produced in this way. A number of interesting and potentially useful features are predicted by Goncalves et al., including (under different conditions of pump-probe relative phase and power) the complete extinction of the probe, amplification of the probe and generation of extremes of antibunching and bunching, i.e., $g^{(2)}$ approaching zero or infinity. The predictions for transmitted power and $g^{(2)}$ can be given in terms of a single parameter, an effective coupling efficiency suggesting that interference can be used to make up for geometrical and technical limitations on the coupling to single atoms.

We use a single atom far-off-resonance trap in a “Maltese cross” geometry of four high numerical aperture lenses [2] to realise the interaction between a ^{87}Rb atom, a strong pump beam, and a weak probe beam as described in the proposed scheme [1]. We will present a scheme for using the transmission measurement not only to show the interference effects but also to sort individual atoms based on the relative pump-probe phase at the moment of measurement, thus achieving the post-measurement phase stabilisation necessary for the $g^{(2)}$ measurements.

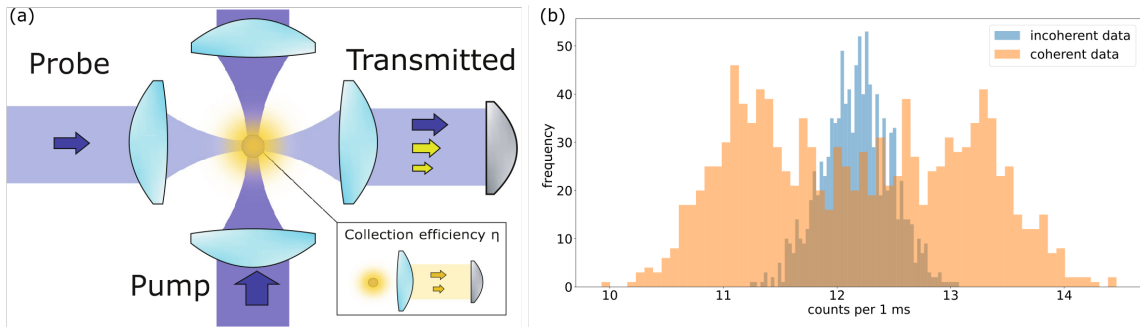


FIG. 1: (a) A strong pump beam excites a single atom acting as a single two-level emitter, while a weaker probe beam is also focused on the atom [1]. (b) Observation of phase-sensitive $g^{(1)}$ correlations in the transmitted probe beam. The blue histogram shows collected photons per millisecond averaged over the pump-probe phase, and the orange histogram shows the same with a nearly constant phase. The resulting arcsine-like distribution makes evident the interference of laser and resonance fluorescence light.

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Beyond Single-Atom Coupling: Self-Organization through Cavity-Induced Atom-Pair Interactions in a Fermi Gas

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Engineering strong interactions in fermionic quantum systems through light-matter coupling enables the exploration of novel phases of matter and the creation of highly correlated states with applications in quantum communication, computation, and metrology. While single-atom-photon coupling has received considerable attention, the collective excitation of atom pairs by single photons can unlock fundamentally new regimes of correlated many-body dynamics [1,2]. Here, we develop a theoretical framework to describe fermionic atoms in an optical cavity, where each photon interacts simultaneously with a pair of atoms. This pairwise coupling induces an effective atom-atom interaction mediated by the photon field, which we show can lead to spontaneous breaking of translational invariance and self-ordering of the atomic ensemble. By analyzing the structure of the ordered state as a function of pump and atom-atom interaction strength, we map out a phase diagram, unveiling nontrivial solutions that signal transitions between distinct quantum phases. Our results demonstrate how cavity-mediated pair interactions in fermionic ensembles can be harnessed to realize and control emergent ordered phases, paving the way for further studies of exotic light-induced phenomena and the development of novel quantum technologies.

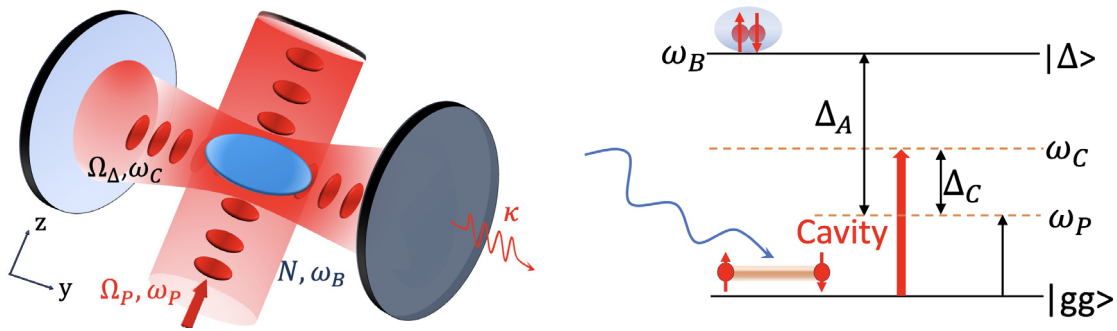


Fig. 1: Left: Schematic diagram for the transversal pumping in the cavity. A fermionic cloud inside an optical cavity is pumped by a laser with frequency ω_P transversely. The coupling between the atomic cloud and the cavity field is captured by the single-mode coupling strength Ω_Δ . Right: The diagram of the energy levels relevant of pairs of atoms gg and a molecule Δ . By Δ_A and Δ_C we denote detunings from the molecular state with energy ω_B and cavity photon energy ω_C , respectively.

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Phase Diagram of the Disordered U(1) Quantum Link Model Created by Ultracold Alkaline-Earth-Like Atoms on a Two-Leg Ladder

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Lattice gauge theories (LGTs) are a successful theoretical framework to regularize strong-interacting-field theories, and therefore they became the bedrock of our current understanding of three of the four fundamental forces in nature. The cornerstone of LGTs is local invariance of the Hamiltonian of the system under a symmetry that describes the force under consideration (either Abelian, like U(1) in QED, or non-Abelian, like SU(3) in QCD).

In the recent decade it became experimentally feasible to simulate LGTs in a laboratory setup of condensed matter physics, using Rydberg atoms, trapped ions, superconducting quantum circuits, and Josephson junctions. This opened a prospect to experimental study of many intriguing but yet hitherto unfeasible phenomena.

A peculiar experimental protocol was implemented in Ref. [1] for simulation of spin-1/2 U(1) quantum link model. The protocol is based on placing ultracold ¹⁷¹Yb or ⁸⁷Sr atoms in their ground (¹S₀) and metastable excited (³P₀) states into optical lattice potential. The emerging Hamiltonian can be mapped to LGT model on a ladder with half-filled fermionic matter (analogous to electron-positron pairs in QED) and spin-1/2 gauge links:

$$H = m \sum_{i=1, \dots, N_x} \sum_{j=1,2} (-1)^{i+j} \psi_{(i,j)}^\dagger \psi_{(i,j)} - \sum_{i=1, \dots, N_x-1} \sum_{j=1,2} [\psi_{(i,j)}^\dagger U_{(i,j),(i+1,j)} \psi_{(i+1,j)} + \text{h.c.}] -$$

$$- J_y \sum_{i=1, \dots, N_x} [\psi_{(i,1)}^\dagger U_{(i,1),(i,2)} \psi_{(i,2)} + \text{h.c.}] - \sum_{i=1, \dots, N_x} \delta J_y^i [\psi_{(i,1)}^\dagger U_{(i,1),(i,2)} \psi_{(i,2)} + \text{h.c.}] \quad (1)$$

with local charge conservation constraint at each fermionic site (Gauss' law). The fermionic mass m and the hopping strength J_y along y -axis are derived from the parameters of the optical lattice potential as well as interactions and chemical potentials of the atoms in ground/metastable states (the hopping along x -axis is rescaled to 1). In realistic situation the entire statistical ensemble of such Hamiltonians must be considered, which is reflected in the random uniform disorder of the hopping strength: $\delta J_y^i \in [-\delta J_y, \delta J_y]$ with $\delta J_y \leq J_y$.

The phase diagram of the Hamiltonian (1) without disorder ($\delta J_y = 0$) was discussed in detail in Refs. [2, 3]. At $m \neq 0$ the system exhibits two phases with nonzero vorticity of its plaquettes: vortex-antivortex (VA) phase at small hopping strength and vortex-zero flux (V0) phase at large hopping strength. Moreover, it also exhibits a symmetry protected topological (SPT) phase with vanishing long-range parity order at $m = 0$ around $J_y = 1$. The transition between the VA phase and the V0 phase is second-order and has Ising universality class.

We address the phase diagram in presence of disorder ($\delta J_y > 0$) using density matrix renormalization group (DMRG) method. It allows for relatively fast and highly precise simulation of the ground state of the system of almost arbitrary size. In particular, we demonstrate it by evaluation of long-range parity order O_P in the system. While at $\delta J_y = 0$ and $m = 0$ we obtain $O_P = 0$ up to machine precision, at $\delta J_y > 0$ the long-range parity order $\frac{O_P}{\delta J_y} \sim 10^{-3} > 0$, which means breaking of Z_2^R reflection symmetry of the system, and thus the SPT phase is destroyed by the disorder.

On the other hand, we confirm that the other two phases, the VA phase and the V0 phase, are robust even to large disorder (in the VA phase the system just acquires residual longitudinal magnetization $S_L > 0$). We address the transition between these two phases for $\delta J_y > 0$ at several fixed nonzero values of m . In particular, for $m = 0.25$ the transition remains of Ising universality class up to a relatively large disorder strength $\delta J_y \simeq 1.4m$ (with discontinuous jump of the longitudinal magnetization and slight shift of the transition point). However, at $\delta J_y > 1.4m$ we observe almost linear dependence of the longitudinal magnetization S_L on the hopping strength J_y for any system size, and the transition apparently changes to first-order.

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Realizing Integer and Fractional Quantum Hall states with a few rapidly rotating Fermions

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The fractional quantum Hall (FQH) effect exhibits remarkable states that due to strong correlations and topological nature host exotic properties such as fractionally charged quasi-particles and anyonic exchange statistics. Realizing these states in scalable engineered systems holds great potential for deepening our understanding of their microscopic origins, yet it remains a challenge. One fundamental class of FQH states is represented by the celebrated Laughlin wavefunction, which describes a strongly correlated state in which the interaction energy is minimized by incorporating the relative angular momentum between all constituents.

Here we present the direct realisation of the two-particle Laughlin wavefunction by rapid rotation of two interacting spinful fermions in a tight optical tweezer [1]. We owe this result to our newly established experimental tools allowing us to precisely shape and modulate our optical potentials using coherently interfering laser fields [2]. Using a single atom and spin resolved imaging technique we sample the Laughlin wavefunction and reveal its distinctive features: a ground state distribution in the center-of-mass motion, a vortex distribution in the relative motion (see Fig. 1), correlations in the relative angle of the two particles, and the suppression of inter-particle interactions.

Building on this technique, we show recent results on larger systems: we realize a two-component integer quantum Hall (IQH) state comprising 3+3 spinful fermions and observe a hallmark feature of IQH states – a uniform flattening of the density distribution. Together with the tunability of interactions, this brings within experimental reach the atom-by-atom assembly of larger FQH states and the observation of a precursor of a quantum phase transition between IQH states of weakly interacting fermions and FQH states of interacting bosonic molecules.

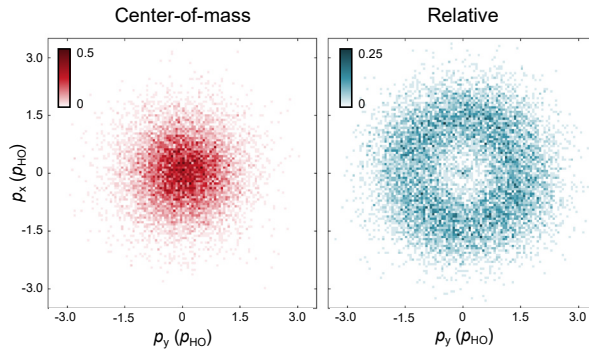


Fig. 1: Normalized momentum-space density in center-of-mass and relative coordinates. The center-of-mass motion has a Gaussian shape. The angular momentum is incorporated in the relative motion of the particles, resulting in an azimuthally symmetric vortex distribution of the density. Note that a small admixture $\sim 1\%$ of a Feshbach molecule is visible as a peak at zero relative momenta. Figure from [1].

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Poster session

Monday



Monday

Poster sessions



Quantum rotor in a two-dimensional mesoscopic Bose gas

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The angulon quasiparticle provides a powerful framework for describing a rotating impurity immersed in a quantum many-body environment [1]. It has been used to describe experimental data in systems such as molecules embedded in superfluid helium nanodroplets [2]. Theoretical research also predicts that the angulon emerges in other settings involving impurities with angular momentum, such as molecular ions in ultracold gases [3] and charge-transfer excitons in lead halide perovskites [4].

In our study, we explore the formation and stability of the angulon quasiparticle in a system of a molecular quantum rotor interacting with a two-dimensional Bose gas. Our methodology allow us to study this system in the crossover from few- to many-body physics. We demonstrate that angulon-like behavior emerges when the surrounding bosonic cloud is sufficiently large to effectively screen the rotor. However, we also show that as the system size increases further, or as its angular momentum becomes large, the angulon picture gradually breaks down. In this regime, the system is instead governed by collective excitations of the Bose gas, marking a transition from a quasiparticle description to a many-body-dominated dynamics.

In addition to characterizing this crossover, we will discuss potential directions for future research, particularly the role of nonlinear excitations such as solitons and vortices, which may emerge due to rapid impurity rotation. These findings offer insights into the interplay between few- and many-body physics and open new possibilities for studying impurity dynamics in ultracold gases. The talk will be based on our recent work [5].

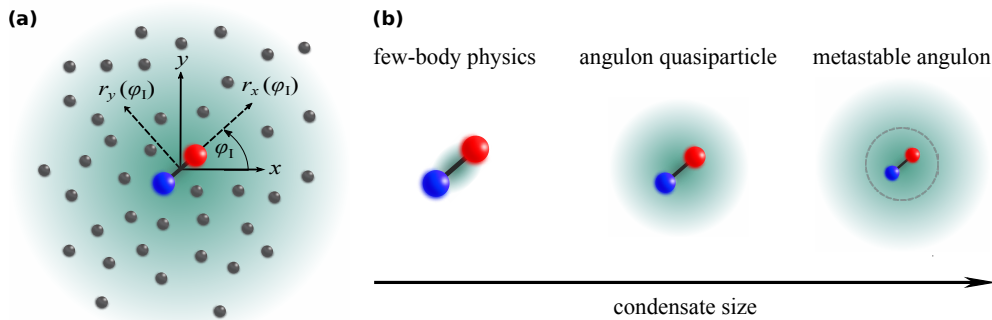


Fig. 1: Schematic representation of our study. Panel (a) shows a molecular linear rotor in a two-dimensional system of bosons. Panel (b) illustrates regimes of the system in panel (a) depending on the number of bosons, N : a few-body state, an angulon state, and a collective excitation state.

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Interaction-based and imaginary time-based bosonic pairing mechanisms

Mon – 2

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We compare two kinds of bosonic pairing, with two different sources: second order terms in the series expansion of the correlation function and the density-induced tunnelling interaction. Both types of pair condensate strengthen the single condensate phase, increasing the critical temperature of bosonic condensation. Since they stem from two different mechanisms but can conceal each other we prepare protocol to distinguish between them. We apply the self-consistent harmonic approximation to the quantum phase model with single and pair condensation terms to study the thermodynamics of both kinds of pairing and add synthetic magnetic fields into the systems to look for possible ways to differentiate between the two kinds of pair condensate in experiments.

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Valid and efficient entanglement verification with finite copies of a quantum state

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Quantum entanglement is long recognised as an important prerequisite of modern quantum technologies. Its detection is accordingly a well-studied topic with a plethora of different methods available. The field has evolved towards strategies directly applicable to experimental data which inevitably is limited to a finite number of detection events. Interestingly, the analysis of small data sets also allows to detect entanglement, see e.g.[1,2,3,4]. Due to

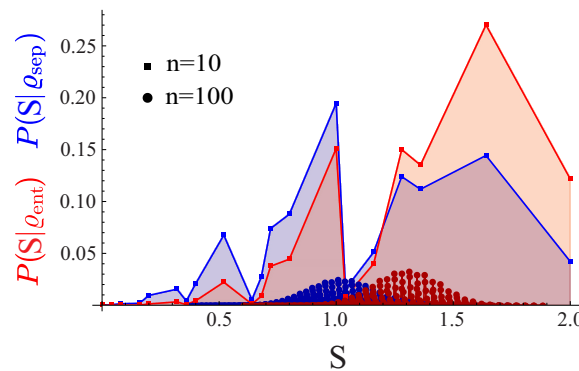


Fig. 1: Probability distributions for obtaining a specific value of a certain nonlinear entanglement witness S with finite statistics. The witness uses only two correlation measurements, each estimated with $n = 10$ (squares) or $n = 100$ (circles) copies of the states. The probability distribution given an entangled state is marked in red, while the blue color corresponds to the worst-case separable state. For larger statistics, the two distributions have small overlap making it easy to verify that an entangled state was prepared. For smaller statistics the overlap is significant and care has to be taken even if big values of the witness are observed.

their finiteness, any conclusion about our state is, however, inevitably probabilistic. By far the two most prominent ways to quantify the validity of such a probabilistic statements are the confidence and the credibility, respectively related to the Frequentist and Bayesian approaches.

We showed explicitly that for small data sets it is necessary to consider not only $P(Q|\text{sep})$, i.e. the probability of a separable state to yield particular values of the witness Q , but also $P(Q|\text{ent})$ of entangled states. This is illustrated in Fig. 1, which shows that for smaller statistics one is required to go to more and more strict criteria to reliably distinguish between results compatible with entangled and separable states. Thus, confidence or credibility is not the only figure of merit and we argue that one also has to include the *efficiency*, i.e. $P(Q|\text{ent})$, of the method as an integral part of any useful measurement scheme. We have introduced a universal procedure that allows the extension of any entanglement witness to the domain of finite statistics. Based on probability distributions for finite copies correlations we defined the measures of validity and efficiency, applicable to any entanglement detection scheme, from the points of view of both Frequentist and Bayesian interpretation. As an example, we derive the optimal number of measurement settings and distribution of clicks per setting for a linear and nonlinear witnesses that guarantee high validity and efficiency of entanglement verification with only 20 copies of a noisy N qubit GHZ state. The methods introduced are directly applicable to raw data and should be especially helpful for a resource-efficient estimation of the performance of a known apparatus subject to variations of external parameters or in multipartite experiments with rare detection events, e.g., multi-photon setups based on coincidence clicks.

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Double unstable avoided crossings and complex domain formation in anti-ferromagnetic spin-orbit coupled spin-1 condensates

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The realization of spin-orbit coupled spin-1 Bose-Einstein condensates offers a highly versatile platform to explore novel quantum phenomena, owing to the tunability of coupling strength and atomic interactions [1,2]. Here, we numerically and analytically analyze the impact of spin-orbit and Rabi couplings on the dynamical stability of spin-orbit-coupled spin-1 Bose-Einstein condensates for ferromagnetic (FM) and antiferromagnetic (AFM) interactions. We employ Bogoliubov-de-Gennes theory to determine the collective excitation spectrum and characterize the dynamical stability regime via modulational instability. For AFM interactions, the eigenspectrum reveals the presence of both stable and unstable avoided crossings (UAC), with the first-excited branch undergoing a double unstable avoided crossing. This behavior was earlier reported in AFM interactions in the presence of the magnetic field [3,4]. In contrast, for ferromagnetic interactions, only a single UAC is observed, occurring between the low-lying and first-excited branches [5]. The eigenvectors demonstrate a transition from density-like to spin-like behaviour as the collective excitation shows the transition from stable to unstable mode for both the FM and AFM interactions. In the multi-band instability state, eigenvectors display spin-density mixed mode, while they show a spin-flip [6] nature in the avoided crossing regime. Our analysis suggests that spin-orbit coupling enhances the instability gain, while Rabi coupling tends to play the opposite role. Finally, we corroborate our analytical findings of stable and unstable regimes through numerical simulations of the dynamical evolution of the condensates, by introducing the perturbations upon quenching the trap strength. The dynamical phases show the formation of complex domains with AFM interaction [4], which may be attributed to the presence of the double unstable avoided crossings in such systems.

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Enhancing Sensitivity Using Uncorrelated Initial States

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A scheme utilising a set of double-well potentials loaded with Bosonic particles is proposed to enhance the Quantum Fisher Information (QFI). We consider M double-wells aligned along one axis (1D), and each double-well is populated on average with $\bar{n}$ bosonic particles as shown in Fig. 1. We first do the mixing between the adjacent modes of two double-wells, and then independent rotations along $\hat{J}_j^{(i)}$ where $j \in \{x, y\}$. The generator of the interferometric transformation is $\hat{h} = \sum_{i=1}^M \hat{J}_j^{(i)}$, as all $\hat{J}_j^{(i)}$ commute, we can write QFI as follows [1]

$$F_q = 4\Delta^2 \hat{h} = 4 \sum_{i=1}^M \Delta^2 \hat{J}_j^i + 8 \sum_{i \neq l=1}^M (\langle \hat{J}_j^i \hat{J}_j^l \rangle - \langle \hat{J}_j^i \rangle \langle \hat{J}_j^l \rangle). \quad (1)$$

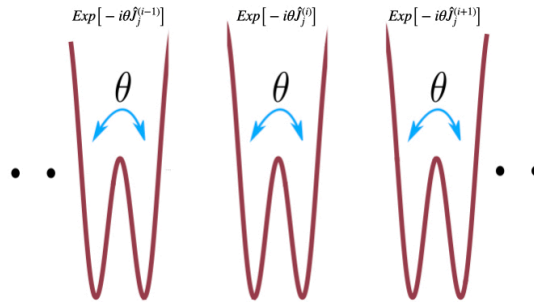


Fig. 1: An array of M double-well potentials subjected to interferometric transformation $\text{Exp}[-i\theta\hat{J}_j^i]$ acquiring same phase θ .

A key finding of this study is that employing uncorrelated initial states $\bigotimes_{i=1}^M |n, 0\rangle^i$ results in a sensitivity enhancement equal to that achieved with highly squeezed states $\bigotimes_{i=1}^M |\frac{n}{2}, \frac{n}{2}\rangle^i$ [2]. Using uncorrelated initial states $\rho^{(M)} = \bigotimes_{i=1}^M \sum_{n_i=0}^n p_{n_i} |n_i, n - n_i\rangle \langle n_i, n - n_i|$, we have demonstrated that QFI can surpass the standard quantum limit even in the presence of particle number fluctuations as shown in Fig. 2 [3].

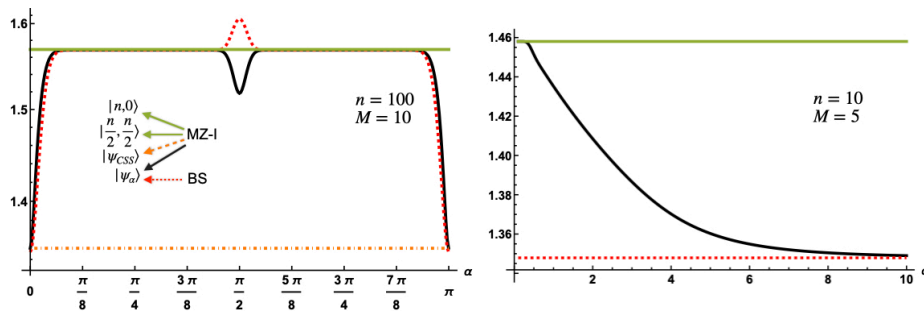


Fig. 2: Figure shows the normalized fisher information $\log_{nM}[F_q]$ with different initial states, where $|\psi_{CSS}\rangle$ is coherent spin state and $|\psi_\alpha\rangle$ is the spin squeezed state. Left panel shows the dependence of F_q on the amount of squeezing, with two interferometric scheme, Mach-Zehnder Interferometer (black solid) and Beam-Splitter (red dotted). Right panel shows the dependence of F_q on particle number fluctuations modeled with gaussian (black) and flat (red dotted) distributions.

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Beating one bit of communication with and without quantum pseudo-telepathy

Mon – 6

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The cornerstone of Bell's theorem is that certain entangled states cannot be simulated with classical theory, namely with local hidden variables (LHV). One of the forefront of the investigations has been the number of bits necessary to simulate entangled states. Previous studies [1-3] have concluded that it is possible to simulate projective measurements on any two-qubit entangled state with one bit of classical communication. Therefore we carried out investigations in higher dimensional quantum systems.

In particular, we study Bell inequalities with a limited number of inputs and outputs, focusing on scenarios in which bipartite correlations resulting from measurements on higher-dimensional states cannot be reproduced with one bit of classical communication. In this study, we constructed Bell-like inequalities that are satisfied by all one-bit models and then we searched for quantum violation. We present several examples for which the one-bit bound has been violated with two-qudit systems. These examples are based on four types of Bell inequalities, including the CHSH inequality [4], the Magic square game [5], the family of CGLMP inequalities [6], and Platonic Bell inequalities [7].

We used novel numerical techniques to compute the one-bit classical bound (L_{1bit}). In some specific cases, L_{1bit} was computed by heuristics, but all other values for L_{1bit} were computed exactly using the so-called branch-and-bound algorithm. The elegant structure of the expressions allowed us to find the exact quantum maximum and set nontrivial upper bounds on the one-bit score.

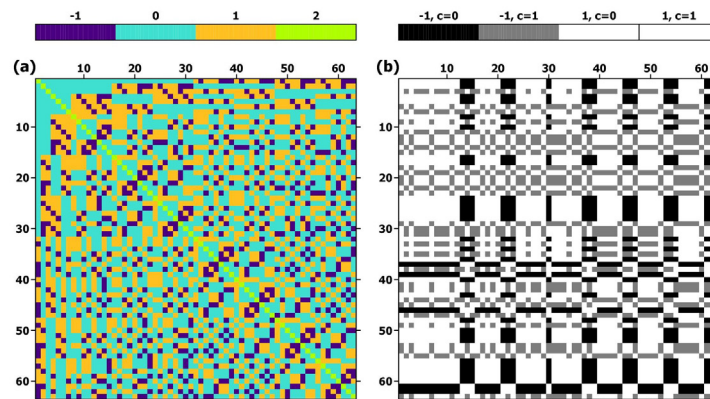


Fig. 1: (a) The 63×63 dimensional E7 Platonic construction. (b) The correlation pattern $E = (E_{xy})$ of the optimal one-bit strategy. Each row x is labeled by the communicated bit $c = 0$ or 1 . For $c = 0$ ($c = 1$) the entries $E_{xy} = -1$ are marked in black (gray), while entries with $E_{xy} = +1$ are marked white.

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Mon – 7

Anderson localization in photonic time crystals**K. S. Eswaran^{1,2}, A. E. Kopaei^{1,2}, K. Sacha²**¹Szkoła Doktorska Nauk Ścisłych i Przyrodniczych, Wydział Fizyki, Astronomii i Informatyki Stosowanej, Uniwersytet Jagielloński, ulica Profesora Stanisława Łojasiewicza 11, PL-30-348 Kraków, Poland²Instytut Fizyki Teoretycznej, Wydział Fizyki, Astronomii i Informatyki Stosowanej, Uniwersytet Jagielloński, ulica Profesora Stanisława Łojasiewicza 11, PL-30-348 Kraków, Poland

Solutions of the wave equations for time-independent disordered media can exhibit Anderson localization where instead of wave propagation we observe their localization around different points in space. Photonic time crystals are spatially homogeneous media in which the refractive index changes periodically in time, leading to the formation of bands in the wave number domain. By analogy to Anderson localization in space, one might expect that the presence of temporal disorder in photonic time crystals would lead to Anderson localization in the time domain. Here, we show that indeed periodic modulations of the refractive index with the addition of temporal disorder lead to Anderson localization in time, where an electromagnetic field can emerge from the temporally modulated medium at a certain moment in time and then decay exponentially over time¹. Thus, we are dealing with a situation where, in a fluctuating three-dimensional medium, the birth and death of waves can occur, and the mechanism of this phenomenon corresponds to Anderson localization.

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Macroscopic diamagnetic levitated optomechanics: feedback cooling towards the ground state

Mon – 8

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Cavity optomechanics, where light interacts with the vibrations of a mechanical resonator via radiation pressure, shows promise for research goals from ultra-precise sensing to exploring the quantum-classical boundary. As sensors, cavity optomechanical systems have sensed gravitational waves at LIGO, been proposed to outperform the most sensitive atomic gravimeters, and used to search for dark matter and new types of short-range forces [1]. To explore the quantum-classical boundary, cavity optomechanical systems formed of levitated trapped silica nanospheres in the femtogram mass range, have demonstrated cooling of the sphere's motion to the quantum ground state [2], a major step towards generating motional superposition states. Such states would enable researchers to explore the interaction between quantum mechanics and gravity. Quantum state generation and sensing are both improved with lower motional temperature; therefore we seek to cool the motion of objects in the milligram mass range, or by a factor $\sim 10^{12}$ more massive than the nanospheres cooled so far.

We propose a cavity optomechanical system combining a large moving mass with the control needed to reach the quantum ground state. Our setup involves a free-space, diamagnetically levitated, macroscopic mirror [3] as the mechanical element (the “tricopter”), with the other end of the cavity formed by a fiber Bragg mirror. Fiber and free space are coupled by a gradient-index (GRIN) lens on the fiber tip [4,5]. The low input noise, low dissipation [3], and ability to trap massive objects of diamagnetic levitation allows for a high-Q, high mass oscillator.

Cooling the mirror will use the Pound-Drever-Hall (PDH) technique [6], which we use in “reverse” to match the cavity's frequency to a reference laser beam. For a cavity with one end fixed and one levitated, locking the frequency immobilizes the levitated end, cooling it. The PDH locking protocol holds a cavity's length stable within $S_L = \frac{\sqrt{hc\lambda}}{9\mathcal{F}\sqrt{P_c}} = 6.9 \times 10^{-18} \text{ m}$ [6], where $\lambda = 1550 \text{ nm}$, $\mathcal{F} = 100$ is the cavity finesse, and $P_c = 10 \text{ mW}$ the laser power. For a 10 mg mirror the zero-point motion (ZPM) is $6.3 \times 10^{-18} \text{ m}$. This suggests that PDH-locking the cavity will stabilize the motion to less than the ZPM, cooling the tricopter into its ground state. This cooling is enabled by the narrow optical linewidth of the cavity creating great sensitivity to changes in the cavity frequency.

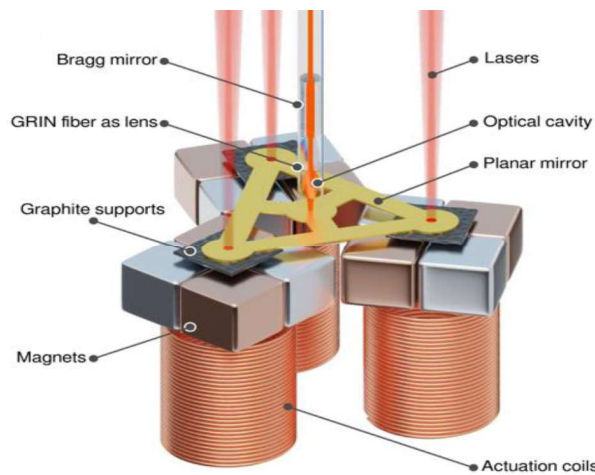


Fig. 1: Our levitated optomechanical system. An optical cavity is formed between the fixed Bragg mirror, inscribed inside an optical fiber, and the mirrored central surface of the movable “tricopter.” The GRIN lens inside the cavity couples the fiber and free-space cavity segments. Three mirrors on the tricopter’s corners allow non-cavity based, low-resolution tilt measurements, via a commercial Picoscale device, which we need to align the cavity. That central cavity’s frequency is locked to a reference laser, cooling the vertical motion. Tilting and vertical motion are actuated with electromagnet-coils beneath each magnet array.

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Superradiant pulse trains in inhomogeneously broadened emitter ensembles

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Coherent, periodic optical pulses underpin crucial technologies in telecommunications, metrology, and optical computing. In traditional lasing, coherence is primarily stored in the electromagnetic field. However, recent advances have shown that coherence among emitters, arising from collective interactions, can enable steady-state lasing [1] and pulse generation [2] with enhanced performance characteristics. Pulse trains emerging from such microscopic collective interactions could similarly unlock new technological possibilities and improved performance in optical devices.

In this theoretical study, we examine a minimal microscopic model consisting of an incoherently pumped ensemble of two-level emitters coupled to an optical cavity. We demonstrate coherent, periodic emission of superradiant pulses specifically enabled by inhomogeneous broadening, which couples the ensemble's collective dipole to otherwise inaccessible dark states, and generates feedback that inhibits steady-state relaxation. The narrowing of the pulse duration, characteristic of superradiance, is observed as the number of emitters is increased. In addition, we show that dephasing mechanisms can serve not only to stabilize coherent pulse trains but, under certain conditions, can also restore steady-state emission, and we delineate the parameter regimes associated with each phase.

As an illustrative application, we finally show that spin diffusion—a common decoherence mechanism in dense, solid-state emitter ensembles—can induce superradiant pulse trains even without external incoherent pumping [3]. These findings illuminate the rich non-equilibrium phenomena in mesoscopic emitter ensembles and could provide novel pathways toward advanced laser technologies.

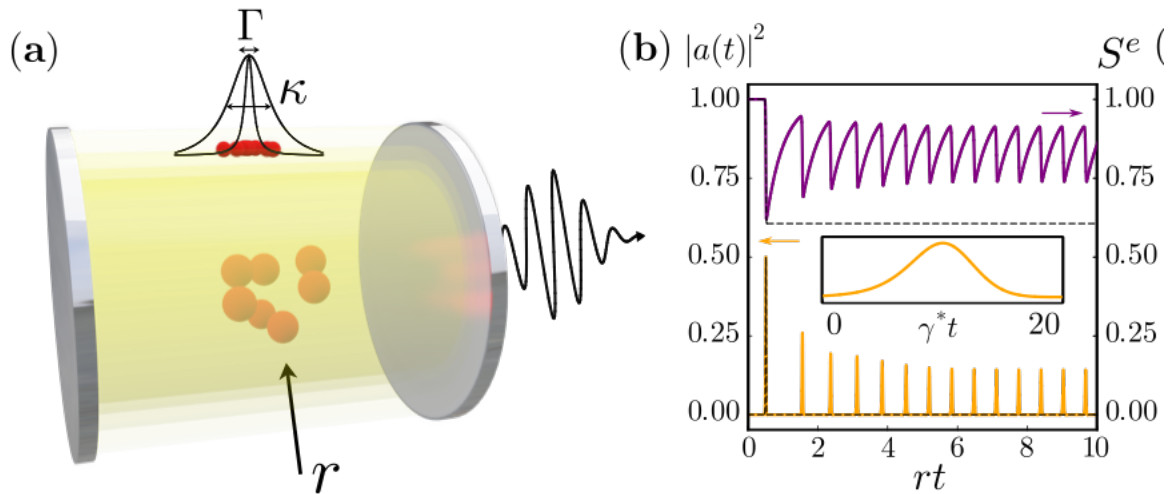


Fig. 1: (a) A cavity of line width κ is coupled to an ensemble of two-level emitters with inhomogeneous line width Γ , which are incoherently pumped with rate r . (b) Cavity intensity $|a(t)|^2$ and ensemble inversion S^e reveal a periodic sequence of pulses in the emission of the ensemble. A single superradiant pulse is shown in the inset.

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Nanoscale stacked ring geometry for efficient excitation transfer

Mon – 10

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Nature relies on ring-shaped light-harvesting (LH) complexes for the highly efficient photosynthetic process. In a much simplified picture, these LH complexes could be theoretically modeled as sub-wavelength rings of optical dipoles, which partially explains their superior optical properties [1-4], for instance, very dark collective eigenmodes and efficient transport of the excitation. Here taking inspiration from the biological nonameric LH2 rings [5-6] [Fig.1(a)], we theoretically propose a stacked three-dimensional (3D) ring structure formed of two-level atoms, with a diameter of 400 nm [7] [Fig.1(b)]. This artificial nanoring features highly efficient inter-layer excitation transfer for certain dipole orientations [Fig.1(c),(d)] within the geometry, in particular, from the sparse to the dense ring layer of quantum emitters, when operated at zero temperature [7]. Our findings are useful for future nanophotonic designs across various platforms, operating at cryogenic temperature where interacting dipole description would remain valid and dominant.

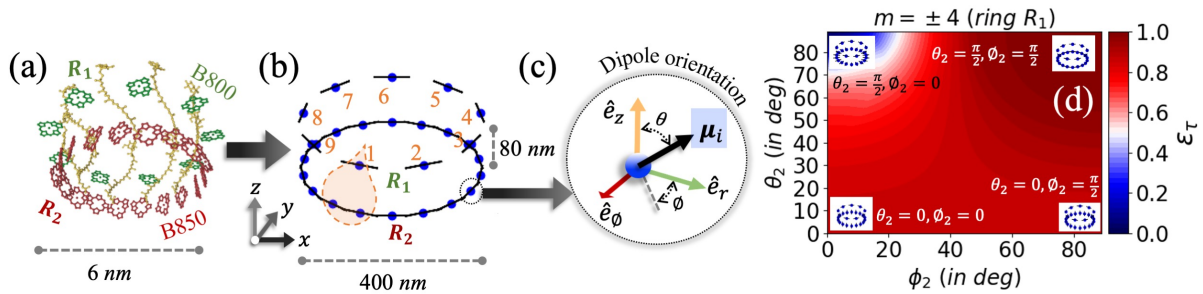


Fig. 1: (a) Biological LH2 complex [taken from [8] (flipped vertically for the analogy)], (b) Bio-inspired nonameric 3D ring structure with ring layers R_1 and R_2 [7]. Small black-solid lines indicate the tangential dipole orientation. (c) Dipole orientation angles (θ , ϕ) of the i^{th} dipole with dipole-moment μ_i [7]. (d) Inter-layer excitation transfer ε_τ ($R_1 \Rightarrow R_2$) for the artificial nanoring [Fig.(b)] with tunable dipole-orientations in ring R_2 [7].

Table 1: Estimated nearest-neighbor distances (r_{ij}) and inter-layer separations (Z_1) (in Å) in the nonameric LH2 [Fig. 1(a)] (from Refs. [6,9]) and LH2-inspired nanoring [Fig. 1(b)] Ref. [7].

Description	Biological LH2	Nanoscale rings
Intra-ring R_1 (Å)	21.3 [9]	1368 [7]
Ring $R_{2a(b)}$ (Å)	9.2, 9.5 [9]	694 [7]
Inter-ring ($R_1 - R_{2a(b)}$) (Å)	17.6, 18.3 [9]	800 [7], 1059 [7]
Z_1 (Å)	16.5 [6]	800 [7]

Grant acknowledgments: This research was funded in whole or in part by the Austrian Science Fund (FWF) 10.55776/ESP682. We also acknowledge support from Forschungsgruppe FG 5 (FWF); 10.55776/W1259 (FWF) (R.H.); 10.55776/COE1 (quantA) (R.H.); Grant No. PID2020-114626GB-I00 from the MICIN/AEI/10.13039/501100011033 (Government of Spain) (M.M-C).

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Tunable two-species spin models with Rydberg atoms in circular and elliptical states

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We propose a scheme for constructing versatile quantum simulators using ultracold Rydberg atoms in long-lived circular states ($|m_\ell| = n - 1$) and elliptical states ($|m_\ell| = n - 2$). By exciting different subspaces of internal atomic states, the atoms can be used to simulate two effective spin species with different spin-spin interactions. The strengths of transverse and longitudinal spin-spin interactions, both intra- and interspecies, can be controlled within a wide range of values. This setup can be used to simulate two-species spin models or lattice models with two sublattices. We show examples of specific models which can be realized [1].

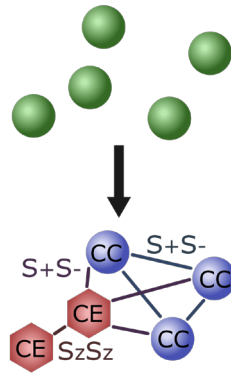


Fig. 1: A visualization of our proposed spin model simulation. We define two distinct two-level subspaces: a pair of circular states, or a circular + elliptical state pair. Each of these subspaces can be interpreted as a pair of spin-1/2 states. By being driven into one of these subspaces, an atom (here represented as a green ball) can simulate one of two distinct “spin species” (represented as blue and red shapes), here called “CC” and “CE”. The dipolar interactions between the atoms map onto effective spin-spin interactions. Different effective spin species have different interaction scales: interaction between two CE spins is dominated by the Ising coupling $\propto \hat{S}_z^1 \hat{S}_z^2$, while interaction between two CC spins, or between CC and CE spins, is dominated by the Heisenberg coupling $\propto \hat{S}_+^1 \hat{S}_-^2$. Nevertheless, by adjusting the atom positions and external electric field, the magnitudes of both Ising and Heisenberg interactions can be manipulated separately for each spin.

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Magic dynamics in many-body localized systems

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Understanding how quantum resources propagate in many-body quantum systems is crucial for achieving universal quantum computation. Nonstabilizerness, also known as quantum magic, characterizes the beyond-Clifford operations needed to prepare a quantum state and constitutes an essential resource, alongside entanglement, for achieving quantum advantage. This work investigates how nonstabilizerness spreads under the dynamics of disordered quantum many-body systems. Using the ℓ -bit model, a phenomenological model of many-body localization (MBL) [2, 3], we present an analytical description of the nonstabilizerness growth in MBL systems. We demonstrate that our analytical formulas describe the nonstabilizerness growth in strongly disordered quantum spin chains; further details are available in Ref. [4] (currently in preprint). Our findings establish a new facet of MBL phenomenology and identify the vital role of the disorder in slowing down the growth of the complexity of quantum states, important for our understanding of quantum advantage. This work was funded by the National Science Centre, Poland, project 2021/03/Y/ST2/00186 within the QuantERA II Programme that has received funding from the European Union Horizon 2020 research and innovation programme under Grant agreement No 101017733.

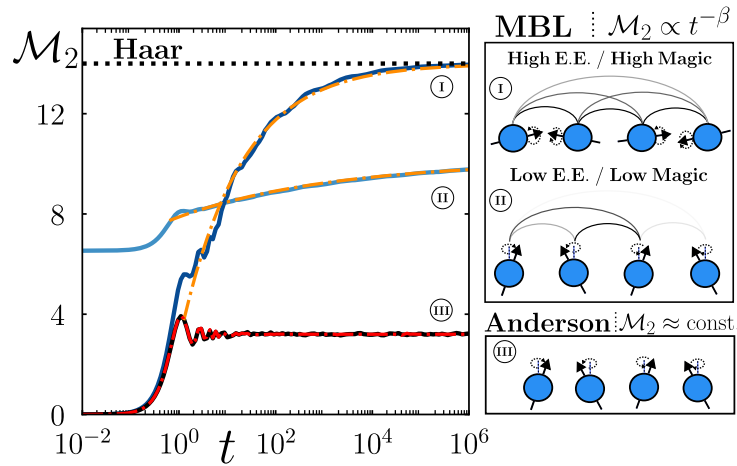


Fig. 1: Magic spreading in disordered quantum systems. In the absence of interactions (III), nonstabilizerness is described solely by spin precession and saturates to $L \log_2(8/7)$ (see Ref. [4]). In the interacting case, slow spin dephasing leads to a power-law growth of nonstabilizerness, $\mathcal{M}_2^{\text{MBL}} = \mathcal{M}_2^{\text{sat}} - c/t^\beta$. For an initial X -polarized state (I), $\mathcal{M}_2^{\text{sat}}$ approaches the Haar value, $c = \ln D$ and $\beta = \chi \ln 2$ (see Ref. [4]). Saturation occurs on a timescale much shorter than that required for the entanglement entropy. For a generic random product state, (II), the growth of nonstabilizerness is limited.

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Hybrid Thermal Machines using Spin-Mechanical Interactions

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Spin-mechanical coupled systems offer exciting opportunities for applications in quantum sensing, simulations, and transduction by leveraging both spin and mechanical subsystems [1, 2]. In this work, we present a framework for developing quantum thermal machines—a quantum battery and a quantum Otto engine—using a single Nitrogen-Vacancy (NV) center coupled to a low-frequency, high-Q mechanical oscillator, with frequency $\omega_m/2\pi = 50$ Hz [3].

These machines are engineered to operate in a regime where the oscillator's frequency is much smaller than the NV center's spin transition and relaxation rates. We enable on-demand, coherent energy transfer between the NV center and the oscillator by employing carefully timed microwave pulses and rapid optical resets to spin. In the quantum battery mode, we demonstrate energy storage in or extraction from the oscillator's long-lived motional states via discrete spin flips.

Furthermore, we demonstrate a spin-driven protocol that facilitates a cooling mechanism to reduce the oscillator's phonon population below thermal equilibrium to single phonon regime, engineering an effective cold bath for the oscillator. Although there have been several works on spin cooling of oscillators [4, 5], our technique is also applicable for oscillators with frequencies much smaller than the spin's decoherence rates. Integrating this spin-cooling mechanism into an Otto cycle while maintaining contact with a hot reservoir enables the realization of a quantum heat engine operating with only a single heat bath. The proposed engine generates mechanical work with near-ideal efficiency in finite time without requiring any decoupling from the external thermal environment.

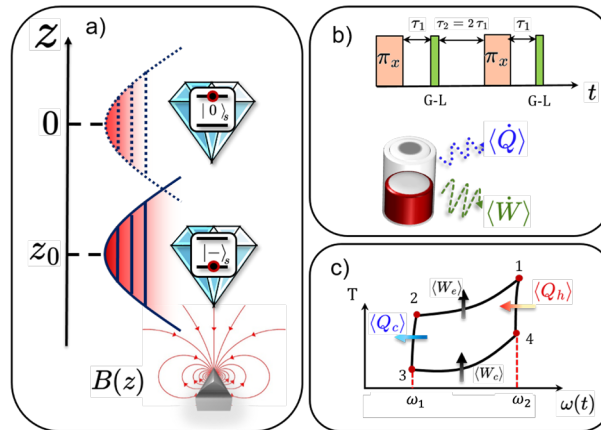


Fig. 1: (a) Proposed Setup: A harmonically trapped diamond containing an NV center is subjected to a gradient magnetic field $B(z) = B_0 - G_z z$. In the high magnetic-field limit, the NV center can be reduced to a spin-1/2 system with states $|0\rangle_s$ and $|-1\rangle_s$. The spin-mechanical coupling $\sigma_z(a + a^\dagger)$ induces a spin-dependent shift in the trap position, enabling the creation of two thermal machines illustrated in (b) and (c). **(b) Quantum Battery:** Energy is stored in the high-quality mechanical oscillator due to the spin-dependent coupling and the long mechanical coherence time. **(c) Quantum Heat Engine:** By adiabatically modulating the mechanical frequency between ω_1 and ω_2 and engineering an effective cold reservoir for the mechanical oscillator, we can enable energy extraction from the mechanical oscillator using a single external thermal bath.

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Toward Spectroscopy 2.0: multichannel dual-comb spectroscopy of complex atoms

Mon – 14

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A diverse selection of atomic systems with varied properties is essential for optimizing sensitivity to specific interactions in fundamental physics experiments, especially in the growing field of searches for new physics using atoms and molecules [1]. Although atomic databases provide valuable references, their coverage remains limited, particularly for rare-earth and actinide elements, because of the extreme complexity of their dense atomic spectra, which pose challenges for both theoretical modeling and experimental exploration. To address these challenges, Spectroscopy 2.0 has been proposed as a transformative framework for modern spectroscopy [2]. It outlines a path forward by combining three core components:

- 1) Massively parallel spectroscopic tools,
- 2) Tunable high magnetic fields to probe new degrees of freedom,
- 3) State-of-the-art many-body theory, powered by modern computation and machine learning.

In this work, we contribute to this vision by demonstrating a multichannel dual-comb spectroscopy (DCS) technique that enables high signal-to-noise ratio, ambiguity-free, broadband spectral acquisition across multiple detection channels simultaneously [3]. In addition, we have implemented a data acquisition system, used in our previous work [4] that is capable of performing gapless averaging of power spectral density spectra with a bandwidth of 125 MHz and a resolution better than 1 Hz. We used this system to investigate samarium vapor, measuring absorption over a 52 nm bandwidth. The experiment resolves a dense set of spectral lines, including several previously unreported ones, showcasing the power of the technique to investigate complex atoms in a massively parallel regime.

Furthermore, we will present a new compact cell design optimized for high magnetic field spectroscopy, suitable for use with various complex atomic species. This design is compatible with extreme field environments, including magnetic fields up to 100 T [5,6], and supports the extension of Spectroscopy 2.0 to previously unexplored regimes. The architecture of magnets used to reach such high fields typically features narrow bores, often only a few centimeters or millimeters in diameter, which significantly limit the physical size of spectroscopy cells. This poses a particular challenge for the evaporation of rare-earth elements, which require high temperatures ($> 1000^\circ\text{C}$).

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Detecting Bell correlations beyond two measurement settings with spin- f systems

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Bell correlations are named after physicist John Stewart Bell, who first described them in 1964. They refer to correlations between the outcomes of measurements, performed on particles sharing quantum state, that cannot be explained by any local hidden variable theory. Bell correlations play a crucial role in the development of quantum technologies, leveraging the unique properties of quantum systems to perform tasks beyond the capabilities of classical technologies, including quantum teleportation, quantum cryptography, and quantum computing. In some applications allowing multisetting Bell scenario which extends the standard one by considering multiple measurement settings per each observe might be profitable.

We explore detection of Bell correlations in spin- f Bose-Einstein condensates generated dynamically from coherent state with a focus on the role of measurement settings. We define protocols for certifying Bell correlations using a data-driven approach [1] for arbitrary numbers of settings. These Bell correlations are then verified using recent experimental results for spin-1 BECs [2]. Our results reveal the fundamental characteristics of the multisetting Bell scenario in spin- f bosonic systems.

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W-Class States—Identification and Quantification of Bell-CHSH Inequality Violation

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The possibility of the creation and manipulation of quantum states is crucial for the development of quantum information theory and its practical applications. In this context, the non-local Bell states are of particular significance. Quantum states that violate the Bell inequality have found a wide range of applications, and nonlocality, as the form of the strongest quantum correlations, is suitable as a resource for quantum information processing.

This study focuses on W-class states, which are of particular relevance in this field. These states find extensive application in quantum information systems, including cryptographic protocols, quantum teleportation, and dense coding.

To analyse the violation of the Bell-CHSH inequality occurring in two-qubit subsystems, we use the quantity introduced by Horodecki et al. [1, 2]. The mutual relations between the Bell-nonlocality parameter and entanglement measures, including concurrence [3, 4] and negativity [5, 6], are also revealed. The mutual relation between two-mode nonlocality parameters in three-qubit systems is also discussed. It is demonstrated that such a system can be a source of both two-qubit states violating and no-violating the Bell-CHSH inequality. Subsequently, the formulas defining the relations between two-mode nonlocality parameters are investigated. Furthermore, the relations between the bipartite negativity, concurrence, and the nonlocality parameter are analysed. The study concludes with the determination of the boundary values of these quantities for states that either violate or do not violate the Bell-CHSH inequality [7].

Acknowledgment. J.K.K. and W.L. acknowledge the support provided by the program of the Polish Ministry of Science entitled ‘Regional Excellence Initiative’, project no. RID/SP/0050/2024/1.

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Mon – 17

Characterizing far from equilibrium states of the one-dimensional nonlinear Schrödinger equation

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We use the mathematical toolbox of the inverse scattering transform to study quantitatively the number of solitons in far from equilibrium one-dimensional systems described by the defocusing nonlinear Schrödinger equation. We present a simple method to identify the discrete eigenvalues in the Lax spectrum and provide a extensive benchmark of its efficiency. Our method can be applied in principle to all physical systems described by the defocusing nonlinear Schrödinger equation and allows to identify the solitons velocity distribution in numerical simulations and possibly experiments.

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Unlocking photodetection for quantum sensing by likelihood-free methods and deep learning

Mon – 18

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Machine learning (ML) algorithms have become powerful tools across various scientific domains, yet their application in quantum sciences often suffers from a lack of interpretability. In particular, ML models are frequently treated as black boxes, making it difficult to extract meaningful insights about their learning process and decision-making criteria. To address this challenge, we compare a trained ML model with the Approximate Bayesian Computation (ABC) method for the task of continuous parameter estimation in a nonlinear optomechanical system probed by photodetection. This system consists of an optical cavity strongly coupled to a mechanical mode what precludes the usage of traditional estimation techniques that rely on the computation of the likelihood to observe a particular click trajectory. ML and ABC serve as natural alternatives, yet we demonstrate the former to outperform the latter in both accuracy and efficiency, primarily due to its ability to exploit quantum correlations encoded in the patterns of photodetector clicks. While ABC provides reasonable parameter estimates, it requires significantly longer computational times, making it impractical for real-time applications. In contrast, once trained, the ML model delivers near-instantaneous predictions, making it particularly advantageous for scenarios where rapid inference is essential. Furthermore, our analysis sheds light on how ML models extract key features from quantum measurement data, contributing to a broader understanding of their interpretability in physics-driven problems. This study highlights the potential of ML for accelerating quantum experiments and suggests new avenues for integrating data-driven approaches with traditional physics-based inference methods.

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Fano Profiles in the Resonance Fluorescence Spectrum of a Quantum Dot Coupled to Phonons

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We study theoretically resonance fluorescence (RF) on a single weakly excited self-assembled quantum dot (QD), coupled to the continuum of phonons. The phonons are a source of non-Markovian, quantum noise that perturbs the energy of the transition to the excited (exciton) state in the QD. We show that moderately strong exciton-phonon coupling (which holds e.g. for InAs/GaAs QDs) leads to a Fano-like line profile near resonant energy, which is due to interplay of a broad phonon sideband (PSB) and a narrow inelastic scattering line stemming from noise-induced transient dynamics. In the weak-coupling limit, the spectral profile becomes an exact Fano shape, where resonant light scattering is totally suppressed. The amplitude of the narrow Fano feature grows linearly with temperature and disappears at 0K; however, due to the super-Ohmic character of the phonon reservoir, its width depends solely on the exciton dephasing time.

Phonon effects in both linear and nonlinear spectroscopy of QDs have been thoroughly studied for years. It has been established that emission, absorption or four-wave mixing spectrum contains a narrow central line (unbroadened by phonons due to their super-Ohmic nature) and a broad phonon sideband, whose shape depends strongly on temperature. For RF under pulsed excitation, a similar structure is predicted for the spectrum [1]. However, our studies of RF under cw excitation with the classical white noise [2, 3] show that noise-induced transient dynamics give rise to non-elastic scattering, manifested by a broadened line at the transition frequency, in contrast to the laser-linewidth-limited Rayleigh scattering feature located at the laser frequency.

Here we use a two-level independent boson model of a QD coupled to longitudinal acoustic (LA) phonons via deformation potential. We solve the Lindblad equation for the evolution of our system in the presence of spontaneous emission in the leading order in optical excitation, while treating phonons exactly. We used the Lax theorem for the two-point autocorrelation function to compute the RF spectrum under cw excitation. Fig. 1(a) shows that, at slightly detuned excitation, the spectrum is composed of a broad PSB and a narrow inelastic feature (elastic scattering line is not shown). The inelastic line has a temperature-independent width, while its strength is proportional to temperature. As the detuning is decreased, the overall scattering intensity grows, and therefore the broad PSB raises (see Fig. 1(b)). Simultaneously, the narrow feature evolves from a mostly absorptive shape via dispersive to a spectral dip around the transition frequency, which results in a considerable suppression of scattering for coupling strengths typical, e.g., for GaAs. The effect can be shown to be a consequence of the reservoir memory (colored noise) rather than its quantum nature.

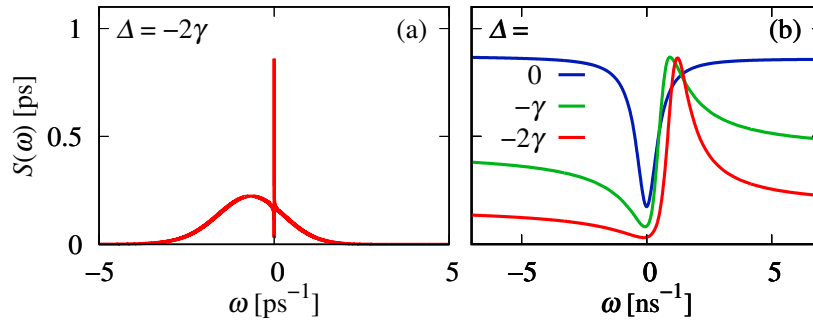


Fig. 1: RF spectrum (without the elastic scattering line) at various laser detunings from resonance (Δ), shown in terms of the exciton decay rate γ . Broad spectral range (a) and zoom into a narrow spectral range around the resonance (b). Results for temperature 5 K. The frequency is with respect to the laser frequency.

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Rotational Cavity Optomechanics Using Atomic Superfluid in a Ring**Sanket Das¹, Pardeep Kumar², M. Bhattacharya³, and Tarak N. Dey⁴**¹*(Presenting author underlined) Okinawa Institute of Science and Technology Graduate University, Okinawa 904-0495, Japan*²*Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany*³*School of Physics and Astronomy, Rochester Institute of Technology, 84 Lomb Memorial Drive, Rochester, New York 14623, USA*⁴*Department of Physics, Indian Institute of Technology Guwahati, Assam 781039, India*

We introduce a hybrid optomechanical system containing an annularly trapped Bose-Einstein condensate (BEC) inside an optical cavity driven by Lauguerre-Gaussian (LG) modes. Spiral phase elements serve as the end mirrors of the cavity such that the rear mirror oscillates torsionally about the cavity axis through a clamped support. The condensate atoms interact with the optical cavity modes carrying orbital angular momentum, creating two atomic side modes. We observe three peaks in the output noise spectrum corresponding to the atomic side modes and rotating mirror frequencies, respectively. The trapped BEC's rotation reduces quantum fluctuations at the mirror's resonance frequency. We also find that the atomic side modes-cavity coupling and the optorotational coupling can produce bipartite and tripartite entanglements between various constituents of our hybrid system. We reduce the frequency difference between the side modes and the mirror by tuning the drive field's topological charge and the condensate atoms' rotation. When the atomic side modes become degenerate with the mirror, the stationary entanglement between the cavity and the mirror mode diminishes due to the suppression of cooling. Our proposal, which combines atomic superfluid circulation with mechanical rotation, provides a versatile platform for reducing quantum fluctuations and producing macroscopic entanglement with experimentally realizable parameters.

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Mon – 21

Ultralong-range Rydberg molecules of Hg atoms

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Ultralong-range Rydberg molecules, composed of an excited Rydberg atom and a ground-state atom, are characterized by large bond lengths, dipole moments, sensitivity to external fields, and an unusual binding mechanism based on low-energy elastic electron scattering. Although Rydberg molecules formed between alkali atoms have received the most attention, the additional complexity found in atoms with more than a single valence electron poses new theoretical challenges as well as new possibilities for control and design of the molecular structure. In this work, we extend the theory of Rydberg molecules to include the additional spin coupling of the Rydberg states of a multivalent atom. We employ this theory to describe the properties of Rydberg molecules composed of mercury atoms. We calculate the potential energy curves of both heteronuclear (Hg^*Rb) and homonuclear (Hg^*Hg) molecules. In the former case, we propose the realization of long-range spin entanglement and remote spin flip. In the latter, we show how long-lived metastable molecular states of Hg^*Hg exist as resonances above the dissociation threshold.

Monday

Poster sessions



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Joint optimization of source and detectors for the discrete-variable quantum key distribution in the presence of strong classical signals

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In the ideal scenario quantum key distribution (QKD) protocols offer unconditional security to its participants. However, in realistic conditions the security is strongly limited by numerous setup imperfections. Since installing dedicated fiber networks solely for the purpose of performing quantum communication is broadly considered to be unreasonable due to the extensive costs, one of the most important practical issues affecting QKD performance is related to the channel noise originating from strong classical data streams propagating alongside quantum signals. In particular, spontaneous Raman scattering phenomenon can easily dominate the other sources of noise and strongly limit the maximum QKD security distance, even when the power of classical signals is significantly reduced. This effect can be especially devastating for the discrete-variable (DV) QKD scenario, in which the quantum signals contain less than one photon on average [1].

Fortunately, the aforementioned problem can be considerably lessened by applying the temporal filtering method, as proposed in Ref. [2]. However, full potential of this method, that could be accessed with proper optimization of the QKD setup, has not been investigated yet. Such a study would be of great practical importance, especially since significant impact of setup optimization on the performance of QKD protocols has already been underlined in a couple of recent articles considering other communication scenarios [3,4].

In this work we fill the aforementioned gap by theoretically analyzing the DV QKD security in the presence of strong classical signals co- and/or counter-propagating with the quantum signal through the same fiber. We apply temporal filtering method to lower the Raman scattering noise and optimize its performance by carefully choosing both the properties of photons produced by the sender's source and the duration of the detection windows established by the receiver. We consider both the prepare-and-measure and entanglement-based types of QKD setup configurations. For both of them we provide fundamental benchmarks on the power of classical signals, above which secure key generation would be impossible even for QKD parties utilizing ideal source and detectors of the quantum signals, with fully optimized characteristics.

Furthermore, as a realistic example we consider the coexistence of quantum and classical communication in the wired connections between the nodes of 6G network infrastructure. For the expected setup parameters in such a scenario we show that full optimization of the setup can extend the maximal security distance by 30 km (almost 50 km), comparing with the case of basic temporal filtering method, without any setup optimization (case of no temporal filtering, with detectors permanently opened). Considering the typical lengths of single links in metropolitan communication networks, such an extension is very significant. As a result, the considered idea of enhancing the security of 6G communication networks with QKD realized between the nodes, can be seen as a promising solution in realistic scenarios.

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Low-power microstructured atomic oven for alkaline-earth-like elements

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Alkaline-earth-like elements are of growing interest for their potential in state-of-the-art quantum sensors, most notably optical clocks. Optical lattice clocks (OLCs) based on ytterbium and strontium have achieved remarkable technological advancement in recent years, reaching fractional frequency uncertainties in the low 10^{-18} range. Although transportable systems have been developed that aim for field deployment and even space applications, they still face challenges in meeting the demanding size, weight and power consumption constraints essential for space operation.

A significant fraction of an OLC's overall power consumption stems from the atom source, typically an effusive oven that requires heating to temperatures up to 400 – 500 °C. Progress towards the reduction of the power consumption has been made with a chip-size atomic oven based on silicon [1]. Here, we present a chip-size monolithic atomic oven based on microstructured fused silica [2], which leverages the very low thermal conductance of fused silica to even further reduce the required heating power. The oven has been manufactured with LIDE[®] (laser induced deep etching). It has a central reservoir that is held by four mounting springs and is heated directly. A laser-structured electrical circuit, in the shape of a Fermat's spiral, on the back side of the chip allows for electrical heating, as well as heating by optical absorption of light.

We characterized the oven by loading an ytterbium magneto-optical trap (MOT) and measuring the MOT loading rate. The MOT is generated by a monolithic pyramid reflector [3], which requires only a single incident laser beam. The oven is placed directly at the outside of the reflector, minimizing its distance to the trap center (Fig. 1). We demonstrate MOT loading rates above 10^8 atoms/s for heating powers below 250 mW. We further demonstrate that the oven can provide a stable flux of atoms when heated electrically, and that trapping and cooling on the narrow triplet transition is possible in this compact setup. Our oven thus constitutes a promising candidate to serve as an atom source for a future highly compact transportable OLC.

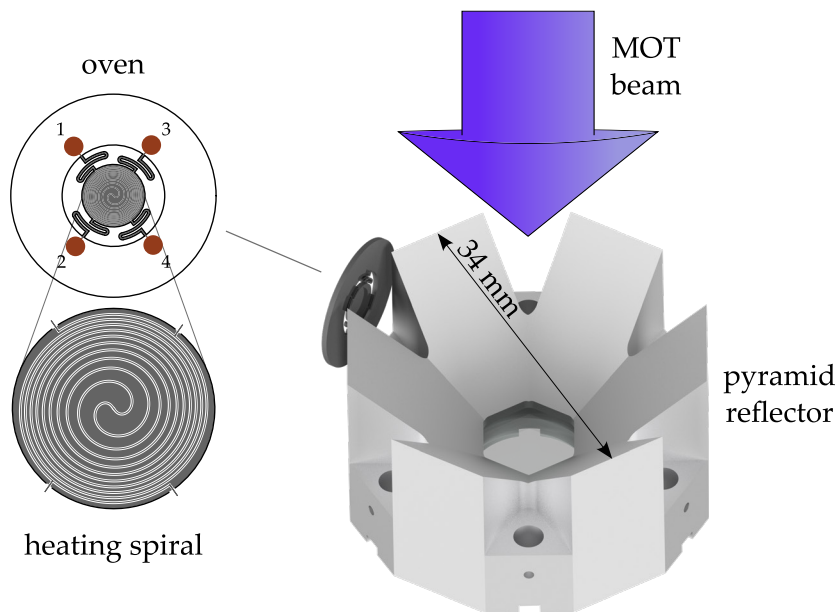


Fig. 1: Experimental setup for loading an ytterbium MOT from the microstructured oven.

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A potassium-39 quantum gas microscope

Mon – 24

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Understanding many-body quantum systems, both in and out of equilibrium, is often computationally challenging due to the large Hilbert space of the systems of interest. This makes quantum simulation very attractive, especially when the relevant observables and their correlations can be measured directly. The Bose-Hubbard model for instance, which describes interacting bosons in lattices, can be well simulated using ultracold atoms loaded into optical lattices. High-resolution imaging can then be used to resolve the occupation of each lattice site, in what is known as a quantum gas microscope.

Here, we present our progress towards building a quantum gas microscope using ultracold potassium-39, to study the Bose-Hubbard model in 2D. We generate a 2D square lattice with a single 1064nm beam in a bowtie geometry and additionally confine the atoms along the vertical direction using a shallow-angle vertical lattice. To readout the system state following some time evolution of the system, we employ Raman sideband cooling at near-zero magnetic field to collect fluorescence on the D1 line. Characterization of our imaging scheme is presented.

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Mon – 25

Renormalization and Low-Energy Effective Models in Cavity and Circuit QED

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The quantum Rabi model (QRM) is a cornerstone in the study of light-matter interactions within cavity and circuit quantum electrodynamics (QED). It effectively captures the dynamics of a two-level system coupled to a single-mode resonator, serving as a foundation for understanding quantum optical phenomena in a great variety of systems. However, this model may produce inaccurate results for large coupling strengths, even in systems with high anharmonicity. Moreover, issues of gauge invariance further undermine its reliability. In this work, we introduce a renormalized QRM that incorporates the effective influence of higher atomic energy levels, providing a significantly more accurate representation of the system while still maintaining a two-level description. To demonstrate the versatility of this approach, we present two different examples: an atom in a double-well potential and a superconducting artificial atom (fluxonium qubit). This procedure opens new possibilities for precisely engineering and understanding cavity and circuit QED systems, which are highly sought-after, especially for quantum information processing.

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Dissipative quantum chaos: foundation and relevance for quantum technologies

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The study of chaos and integrability in open quantum many-body systems is central in many research areas, from high-energy physics to quantum optics, from quantum technologies to condensed matter. To date, dissipative quantum chaos is understood on the basis of the universal predictions of non-Hermitian random matrix theory: in presence of chaos, the generator of the dissipative dynamics (the so-called Liouvillian superoperator) behaves as a large random matrix [1, 2]. In our work, we propose a novel definition of dissipative quantum chaos that allows explaining physical phenomena that would otherwise remain elusive, including recent experimental findings. We regard an open quantum system as exhibiting chaotic behavior if its Liouvillian spectral structure is described by random matrix theory and if this structure significantly impacts individual stochastic realizations of the dynamics, commonly referred to as quantum trajectories [3]. To probe the dynamics of open quantum many-body systems we develop a general, model-independent criterion that we call spectral statistics of quantum trajectories, combining random matrix theory tools with the physical insight provided by single stochastic trajectories.

We apply our theoretical framework to several examples of driven-dissipative bosonic systems, ubiquitous in quantum optical setups. First, we consider a driven-dissipative Bose-Hubbard lattice, the paradigmatic modeling of interacting quantum fluids of light [3, 4]. Our theory turns to be effective in the experimental observation of signatures of dissipative quantum chaos in an open Floquet bosonic system [5]. From a quantum device theory perspective, we show how dissipative quantum chaos can significantly impact the performances of current quantum technology platforms. On one side, we study the dispersive readout of a transmon qubit [6], showing how chaos can appear in the circuit quantum electrodynamics architecture underlying the qubit's readout, enhancing or destroying the instrument's performance. On the other side, we investigate the emergence of chaos in dissipative cat qubit architectures, one of the paradigms for bosonic quantum information encoding. Our study explores the mechanisms leading to the degradation of the cat qubit under quantum chaotic behavior [7].

Our work opens several research directions. Further study is warranted to understand how dissipative chaos can affect the performance of larger quantum computing devices, like, for example, concatenated cat qubits, which are now a reality in the laboratory [8]. Another open question concerns a more general understanding about the connection between classical and quantum chaos in open quantum many-body systems.

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Collective light scattering in an array of dysprosium atoms

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To explore collective light-matter interactions experimentally, we have developed a setup that creates ordered ensembles of dysprosium atoms [1]. Leveraging the rich internal structure of dysprosium, we can measure the atoms' internal states in a single shot. We use this technique to investigate collective dissipation both in the linear optics regime by measuring the collective Lamb shift *at the single atom level*. At high saturation we also investigate the effects of the dipole-dipole interaction using Ramsey spectroscopy [2]. We use a 2 kHz transition to cool the atoms close to their ground state using chirped cooling [3] further enhancing the collective behavior of the atoms. While the typical distance between the atoms is currently of a few λ , the wavelength of the transition, we are working to bring the atoms to a distance comparable to λ by implementing a hybrid tweezer and accordion lattice setup as well as working to load many atoms into a single tweezer.

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Spectroscopic gas temperature and concentration measurements from carbon monoxide line intensities

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After constraining the Boltzmann constant, k , in the International System of Units (SI), the accurate methods previously employed to determine k can be used for the primary thermometry. Among these methods, two optical spectroscopic techniques, namely Doppler broadening thermometry (DBT) and rovibrational line-intensity ratio thermometry (LRT), have undergone intense development in recent years. Although the DBT has shown the best accuracy to date, the LRT can be used in a considerably wider range of gas pressures.

Here we present a LRT-based calibration-free spectroscopic gas temperature and concentration measurement method in which both spectral axes are derived from observed frequencies of high-finesse cavity resonances. This technique, known as cavity mode-dispersion spectroscopy (CMDS) [1,2], links the spectrum to the primary frequency standard. By applying the LRT to the (3-0) vibrational band of carbon monoxide and using *ab initio* calculated line intensities [3], we achieve a temperature uncertainty of 24 mK at 296 K (82 ppm) [4]. The spectroscopic temperature and integrated line areas from several CO lines with intensities differing by more than two orders of magnitude allow us to perform an absolute gas concentration measurement with permille-level relative uncertainties (250 ppm) over a pressure range from 50 Pa to 20 kPa. Additionally, we address current limitations and perspectives for improving the accuracy of spectroscopy [5] and the reference data [6], as well as extending our LRT and amount of substance measurement approach to other spectral bands and molecules.

The research was supported by: the European Partnership on Metrology project 22IEM03 PriSpecTemp; the state budget of Poland, allocated by the Minister of Education and Science under the "Polska Metrologia II" program, project no. PM-II/SP/0011/2024/02.

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A New-Generation Rydberg Atom Quantum Simulator

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We are building a new-generation Rydberg atom array setup for quantum simulations that will replace the existing setup developed at Institut d'Optique over the last decade. With this platform, single atoms are arranged in arbitrary geometries by optical tweezers. Using Rydberg states, it is then possible to implement many-body spin Hamiltonians [1]. Most recent works include the XY spin model [2] and the t-J spin model [3].

I will present the construction of the new-generation setup, that improves several important features of the machine. One major upgrade are the focusing optics, which used to be aspheric lenses on the old setup and are now high NA (0.57) microscope objectives. The field of view is increased from $\pm 15 \mu\text{m}$ to $\pm 150 \mu\text{m}$. We are therefore able to generate larger arrays of single Rb-87 atoms (Fig 1 (b)).

The objective holder (Fig. 1 (a)) is designed to allow for maximum control on the atoms. There are ten electrodes, eight to manipulate the electric field on the atoms with a low voltage and two newly-added high-voltage electrodes to ionize and remove Rydberg atoms. Two pairs of coils under vacuum allow for fast control of the magnetic field inside the science chamber. We installed three perpendicular microwave antennas close to the atoms. Compared to the old setup's single microwave antenna outside of the vacuum, this allows for full control of the microwave polarization. Despite placing that many instruments inside the science chamber, the vacuum-limited lifetime of the atoms in the tweezers is 55 s.

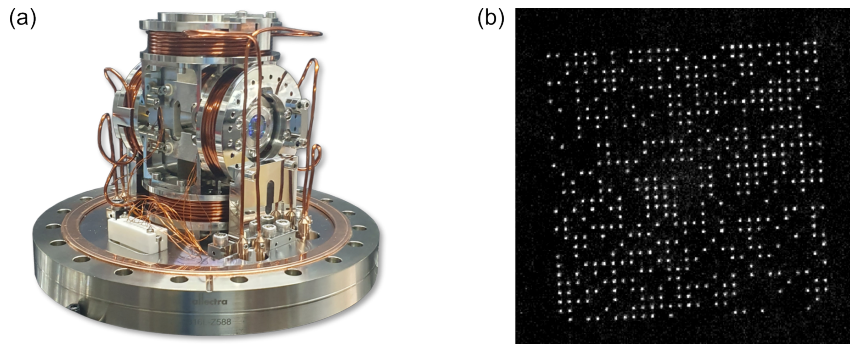


Fig. 1: (a) Microscope objective holder: The holder is placed on a cf-160 flange that is inserted in the science chamber from the bottom. One can see the vertical and horizontal pair of magnetic field coils, as well as one microscope objective placed inside the right horizontal coil. (b) Typical example for a large array of single atoms. Here are 900 traps with a filling fraction of about 41% (370 single atoms).

I will further present some experimental results showing our control over the atoms, such as state preparation and ground state manipulation via 2-photon Raman transition, and implementation of grey molasses for cooling and enhanced loading.

In the future, we will also implement new experimental developments such as quasi-continuous reloading of tweezer arrays and fast, lossless detection. These improvements will increase the programmability of the platform and to enlarge the class of Hamiltonian we can study, reaching a regime of large quantum states very challenging to simulate on classical computer.

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All-fiber microendoscopic polarization sensing at single-photon level aided by deep-learning

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Light polarization plays a fundamental role across various scientific disciplines, from ellipsometry and optical communications to microscopy and sensing. Specifically, the polarization of light emitted by optically anisotropic specimens carries critical information about their material structure and optical properties. However, achieving precise polarization measurements under challenging conditions, such as constrained spaces, low light levels, and high-speed scenarios, remains a significant challenge.

To address this issue, we introduce a real-time polarization measurement method capable of achieving single-photon-level accuracy while providing complete information about the polarization state. Our polarization sensor, which is free of moving components and depicted in Fig. 1(a), utilizes a common few-mode fiber along with a fiber array and a detector array to characterize the input polarization state. This setup is augmented by a deep machine-learning model, reconstructing complete real-time polarization information. The calibrated sensor exhibits exceptional accuracy, achieving an unprecedented infidelity of 8×10^{-4} . This outstanding level of performance has remained remarkably stable for over a month, requiring no additional calibration or network retraining.

We demonstrate the capabilities of our approach through polarization-sensitive scans of an optically anisotropic specimen. The reconstructed polarization scan of a piece of dense connective tissue is visualized through false-colored RGB images (Fig. 1(b)), shown side by side with an intensity image of the same sample region. Additionally, we used the sensor to characterize the twisted nematic liquid crystal transition effect and to analyze the standardized USAF test target.

These demonstrations confirm our polarization sensor's suitability for diverse sensing applications and highlight its invaluable contributions to precise polarization measurements. This sensor opens new frontiers in precise polarization measurement, offering a powerful tool for advanced applications in biomedicine, material research, and beyond.

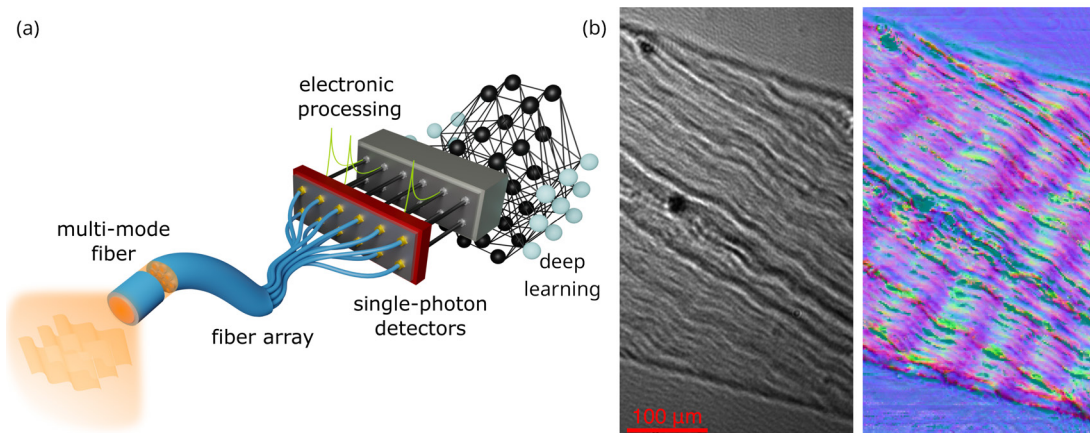


Fig. 1: (a) A visual representation of the all-fiber polarization sensor. (b) Visualization of dense connective tissue: (left) intensity image and (right) a scan using the all-fiber polarization sensor. The resulting Bloch parameters are represented as an RGB false-colored image.

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Towards low-energy structured coherent electron and ion beams

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In recent years, structured matter waves have garnered considerable interest, especially in the context of structured electron beams. Spatially coherent field-emission electron sources are well-established and widely utilized, allowing for precise control over the wavefront of electron beams. These advancements have paved the way for numerous exciting applications in electron microscopy and spectroscopy. Ongoing research continues to explore the potential of structured electrons in quantum experiments and advanced microscopy techniques [1,2].

Our work focuses on developing an experimental setup featuring a tunable low-energy field emission and gas field ion emission source, designed to structure both electron and, eventually, ion beams. The setup incorporates a cryogenically cooled nanotip field emission/gas field ion emission source followed by a 2-meter-long free propagation region. This configuration is expected to produce transversely coherent electron and ion beams, with coherence lengths extending to several micrometers for ions—sufficient for beam structuring using nanofabricated electrostatic components. Initially, we aim to investigate the physics of low-energy vortex electrons and ions, utilizing electrostatic "chopsticks" as a versatile and minimally invasive shaping tool [3].

The experiment is housed in a custom-built vacuum chamber, providing full access to the beamline. Alongside the standard electrostatic deflectors and lenses, a magnetic shielding will be installed along the entire beamline to minimize interference from ambient magnetic fields. This ensures the integrity of the coherent beams throughout the experiment.

The successful realization of a spatially coherent ion source would mark a significant milestone, opening up a new frontier in coherent ion research. The experiment will enable a wide range of experimental possibilities, from probing fundamental physics in composite charged wave systems to advancing ion microscopy techniques. Structured ions, with their significantly shorter wavelengths and unique electric and magnetic properties, hold promise for applications in both fundamental science and technology.



Figure 1: A combined field emission and gas field ion emission source.

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All-optical squeezed BEC generation for microgravity operation

Mon – 32

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Atom interferometers serve as high-precision sensors for quantities like acceleration, rotation, or magnetic fields. The sensitivity of atom interferometers is greatly enhanced by long interrogation times, as they are available in spaceborne applications. Second-long interrogation times favor the employment of atomic Bose-Einstein condensates (BECs) with their well-controlled spatial mode and their slow expansion rates. The sensitivity can be increased even further by employing squeezed atomic ensembles that enable measurements beyond the standards quantum limit.

The INTENTAS project develops a source of entangled atoms that can be tested under microgravity conditions. Microgravity is provided by Hannover's Einstein Elevator, which offers up to 4s of free fall. A key feature is the fast all-optical BEC generation which is performed in a crossed-beam optical dipole trap. In this poster, the status of the project will be presented, which includes operation in microgravity.

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Interplay of localization and topology in disordered dimerized array of Rydberg atoms

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Rydberg tweezer arrays provide a platform for realizing spin-1/2 Hamiltonians with long-range tunnelings and interactions decaying according to power-law with the distance [1]. We numerically investigate the effects of positional disorder and dimerization on the properties of excited states in such one-dimensional system.

$$H = J \sum_{i>j} \frac{1}{r_{ij}^3} (S_i^x S_j^x + S_i^y S_j^y) + \Delta \sum_{i>j} \frac{1}{r_{ij}^6} S_i^z S_j^z,$$

$$r_i = \left(\left\lfloor \frac{i}{2} \right\rfloor + \frac{1}{2} \delta (-1)^{i+1} \right) X_l + i D_{rb} + W_i,$$

Our model allows for the continuous tuning of dimerization patterns and disorder strength. Within the parameter space constrained by our geometry, we identify different distinct ergodicity-breaking regimes - Fig. 1. Notably, one of these regimes exhibits a unique feature where nontrivial symmetry-protected topological (SPT) properties of the ground state extend to a noticeable fraction of states across the entire spectrum. This interplay between localization and SPT makes the system particularly interesting, as localization should help with stabilization of topological excitations, while SPT states contribute to an additional delocalization.

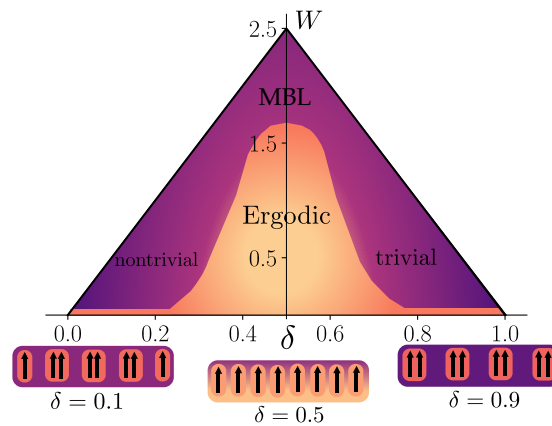


Fig. 1: The qualitative phase diagram for the model in δ, W space where δ is the dimerization parameter in the model and W is the positional disorder strength. $X_l = 10.0, D_{rb} = 1.0$.

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Towards Timetronics with Photonic Systems

Mon – 34

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Periodic driving of systems of particles can create crystalline structures in time. Such systems can be used to study solid-state physics phenomena in the time domain. In addition, it is possible to engineer the wave-number band structure of optical systems and to realize photonic time crystals by periodic temporal modulation of the material properties of the electromagnetic wave propagation medium. We introduce here a versatile averaged-permittivity approach which empowers emulating various condensed matter phases in the time dimension in a traveling wave resonator. This is achieved by utilizing temporal modulation of permittivity within a small segment of the resonator and the spatial shape of the segment. The required frequency and depth of the modulation are experimentally achievable, opening a pathway for research into the practical realisation of crystalline structures in time utilising microwave and optical systems.

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Two-dimensional Bose-Fermi droplets at non-zero temperatures

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We investigate two-dimensional Bose-Fermi droplets at non-zero temperatures. While the formation of these droplets at $T = 0$ is possible under specific conditions governing the mutual interactions [1], it remains of interest whether such structures persist at $T > 0$. To address this question, we employ the Metropolis algorithm within the Grand Canonical Ensemble. We present a temperature-phase diagram illustrating the stability of the Bose-Fermi droplet in isolation, as well as its immersion in a fermion vapor or a boson vapor. The diagram is plotted with respect to the chemical potentials of both bosons and fermions, with temperature as an additional parameter. We assess the stability of the equilibrium state by evolving it in real time.

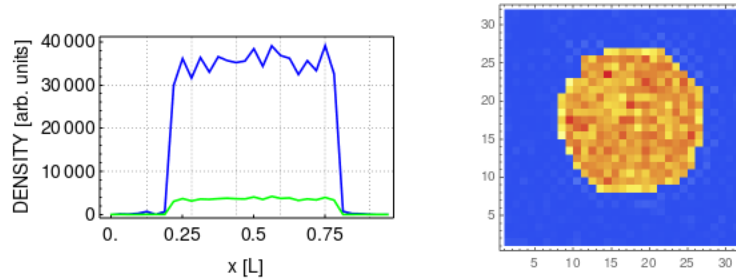


Fig. 1: Left: density cuts along $y = 0$ for bosons (blue) and fermions (green). Right: 2D density distribution for bosons. We consider a system of ^{133}Cs - ^6Li mixture.

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Tracking the ergodic instabilities in the Anderson-“quantum sun” model

Mon – 36

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Recent works [1,2] have confirmed the presence of rare ergodic instabilities in the paradigmatic disordered Heisenberg XXZ chain, suggesting the possible existence of a new phase in the model. These instabilities indicate a significant shift in the many-body localization (MBL) transition to higher disorder strengths compared to predictions from standard finite-size scaling analysis.

In this work, we analyze the connected correlation function in a modified spin-1/2 Anderson-“quantum sun” model [3,4]. The model consists of two components: an Anderson chain of L spins, characterized by the localization length ξ_A , and a small ergodic bath of $N \ll L$ spins. Each spin in the Anderson chain couples to the bath with a strength proportional to e^{-x/ξ_S} , where x denotes the distance to the bath and ξ_S characterizes the interaction range.

The “quantum sun” model exhibits a more robust ergodicity-breaking transition against quantum thermal avalanches [5] compared to paradigmatic MBL models. We demonstrate the presence of ergodic instabilities in the model, highlighting qualitative differences from the XXZ model, particularly in the low-disorder regime of the phase diagram (Fig. 1).

Introducing U(1) particle conservation [4] and the Anderson hopping term makes the model more relevant for experimental realizations, such as ultracold atoms in optical lattices.

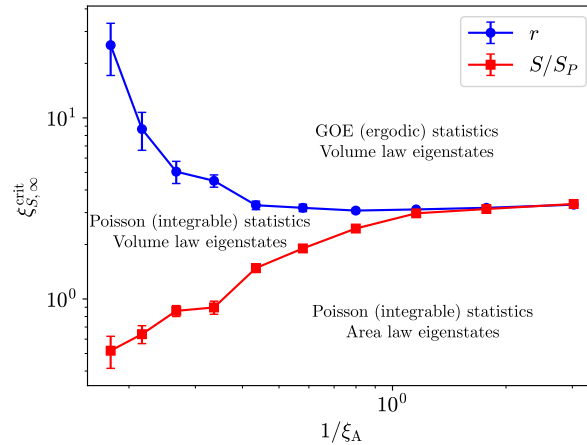


Fig. 1: Phase diagram of the modified Anderson-“quantum sun” model: dependence of critical interaction range ξ_S on the disorder of the Anderson chain $1/\xi_A$, extrapolated to the thermodynamic limit $L \rightarrow \infty$, $N = \text{const}$. The blue line represents a prediction based on spectral statistics of high energy density eigenenergies using so-called spectral spacing ratio $r_n = \min\{(E_{n+1} - E_n)/(E_n - E_{n-1}), (E_n - E_{n-1})/(E_{n+1} - E_n)\}$, whereas red line is based on half-chain entanglement entropy of eigenstates, with the first half consisting of sun spins plus closest Anderson spins, and the second half including the remaining Anderson spins. A region of volume law eigenstates with Poisson spectral statistics emerges at small disorder, the analysis of correlations offers additional insight on this region.

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Investigation of employing Quantum Key Distribution in 6G networks

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In the era of rapid technological advancements, sixth-generation (6G) cellular networks are attracting significant attention due to their capability to transfer massive amounts of information. As security remains one of the most critical requirements for data transmission, it must be an integral part of 6G architecture. While the design of 6G systems is still evolving, it is anticipated that they will support novel use cases with challenging key performance indicators (KPIs), powered by new enabling technologies and network architectures [1].

One promising approach to addressing security challenges in 6G is the use of external providers for secure key distribution between independent entities, such as domain owners, tenants, and service providers. In this regard, quantum communications (QC) offer enhanced security and reduced computational complexity, providing a viable solution for securing 6G networks [2]. Specifically, quantum key distribution (QKD) protocols [3,4] can be leveraged to significantly improve security in 6G environments. However, the integration of QKD with existing fiber-optic classical networks remains a major requirement for widespread adoption. This challenge, driven by cost efficiency and technical compatibility, must be addressed by future generations of quantum networks [5]. The concept of QKD coexisting with classical data traffic was first introduced in 1997 [6] and has since been explored in various network topologies [7,8].

This research investigates the integration of quantum and classical communication in wired connections between elements of the 6G network infrastructure. We analyze the impact of Raman scattering and crosstalk from classical data traffic on QC security, considering both C-band and O-band as potential quantum channel options. Through numerical simulations, we compare the lower bounds of key generation rates achievable with different source types, both in the asymptotic and finite-key-size regimes. The expected performance of QKD is evaluated under realistic 6G network conditions, taking into account key parameters such as classical bit rates, signal power levels, wavelength-division multiplexing (WDM) channel isolation, and Raman scattering cross-section.

Our results demonstrate that, despite higher Raman noise, placing quantum signals in the C-band allows for secure key generation over significantly longer distances than the O-band solution, unless very strong crosstalk suppression is applied and ultra-low-noise detectors are utilized by the QKD parties. For a standard classical signal bit rate of 10 Gbps and typical network setups, proper optimization of the QKD scheme enables secure key generation over distances of up to 100 km in the C-band and 60 km in the O-band. These distances are sufficient for secure communication within standard metropolitan networks, reinforcing the feasibility of quantum-secured communications in future 6G networks.

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High-fidelity heterodyne cavity ring-down spectroscopy of HD line shape

Mon – 38

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Molecular hydrogen (H_2) and its isotopologues serve as benchmark systems for searching for new physics beyond the Standard Model, testing models of molecular collisions, determining the proton-electron mass ratios, investigating potential fifth forces, and validating relativistic and quantum-electrodynamical theories. Many precise measurements of molecular hydrogen transition frequencies have been performed in recent years, e.g., saturation spectroscopy [1] and molecular beam double resonance spectroscopy [2] leading to accuracies at the 20 kHz level and 13 kHz level (the most accurate to date), respectively. In addition to line position, accurately determined line intensities and collision-induced line-shape parameters under conditions of varying temperatures, pressures, and the presence of perturbers are crucial for astrophysical studies, especially for studying the atmospheres of planets and exoplanets. Here, the proper modeling of the spectral line-shape needs an approach going beyond the ordinary Voigt profile.

Achieving high experimental accuracy is another challenge in the line-shape study. Popular cavity ring-down spectroscopy (CRDS) offers ultra-high precision, reaching below 0.01%, but its accuracy is often limited to around 5% due to uncertainties in light intensity measurements. To address this limitation, we developed heterodyne cavity ring-down spectroscopy (HCRDS) method [3] which utilizes the optical frequency information embedded in the ring-down cavity's electromagnetic field. Instead of relying solely on decaying light intensity measurements, this approach involves heterodyne detection of the ring-down signals followed by Fourier analysis. Precise determination of the frequencies of the optical cavity modes as well as cavity mode widths in HCRDS enables to extract simultaneously high-accuracy dispersive and absorptive spectrum of the gas sample. Using the HCRDS method, we attained sub-per-mil accuracy, validated by *ab initio* CO line intensity measurements and HD line-shape analysis.

To analyze the P(3) 2-0 transition of HD, we performed a complex-valued multi-spectrum fit to the absorption and dispersion HCRDS spectra, in which we included various collision line-shape models. In H_2 and its isotopes, non-Voigt effects are significant due to the unusually strong Dicke narrowing and the considerable speed dependence of collisional broadening and shifting [4]. We have shown that the well physically justified speed-dependent billiard-ball profile (SDBBP) [5] and β -corrected [6] partially-correlated quadratic speed-dependent hard collision profile describe the velocity-changing collisions similarly and reproduce the experimental HD spectrum with per-mil-level accuracy. We have demonstrated an excellent agreement of the HD line position with a recent study using vibrational saturation spectroscopy [7]. Moreover, for the first time, the experimentally determined line-shape parameters have validated the fully *ab initio* calculated HD line shape with high accuracy.

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Cooper-pair splitting enabled by the Quantum Geometry of Multifold Topological Bands

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Cooper pair splitters (CPSs) are hybrid nanodevices that harness the inherent entanglement of Cooper pairs in a superconductor. In these devices, a Cooper pair—composed of two electrons in a spin-singlet state—is spatially separated so that each electron is injected into a different conducting channel, thus preserving their spin entanglement [1]. Recent theoretical and experimental work has explored the integration of CPSs into circuit quantum electrodynamics (QED) platforms. In such hybrid systems, the AC Josephson effect can be exploited to induce coherent oscillations in the superconducting phase, which in turn drive transitions involving Andreev-bound states. These transitions have been shown to mediate the conversion of electronic entanglement into frequency-entangled photon pairs, a process that is highly promising for on-chip quantum communication [2,3]. Typically, CPS devices are realized in low-dimensional systems—such as quantum dots, semiconductor nanowires, carbon nanotubes, or nanoribbons—where strong electron confinement and discrete energy spectra facilitate efficient Cooper pair splitting. [4].

A recent discovery of chiral fermionic valves provides a new platform to achieve Cooper-pair splitting utilizing the quantum geometry of topological bands.[5] A chiral fermionic valve spatially separates the transport in chiral topological states into Chern-number polarized topological states. Hybridizing these chiral topological states with superconductors enables long-range phase coherence of Cooper pairs. Coupling the macroscopic phase coherence of Cooper pairs with the chiral behaviour of quasi-particles in topological phases provides us with new degrees of freedom (DOF). Understanding these DOFs and developing strategies to manipulate them is essential to create a Cooper-pair splitter. In this poster, I will introduce a strategy for Cooper pair splitting utilizing the quantum geometry of topological bands of multifold topological metal in a Mach-Zehnder Interferometer shown in Fig. 1. The experimental approach is based on focused-ion beam crystal micro-sculpting to utilize the non-trivial quantum geometry of topological bands during electrical transport measurements.

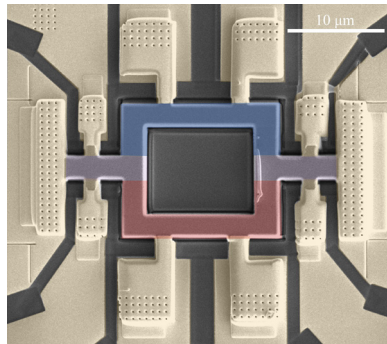


Fig. 1: False-coloured SEM image of the microstructured device of PdGa made using focused-ion beam techniques, depicting a chiral fermionic valve enabled Cooper-pair splitting.

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Thermal melting of a vortex lattice in a quasi two-dimensional Bose gas

Mon – 40

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In the context of quantum simulation, there is a profound analogy between a two-dimensional system of neutral atoms in fast rotation and the problem of 2D electrons in a magnetic field, providing a mapping with the quantum Hall effect [1]. Here we present the first observation of the thermal melting of the vortex lattice present in a rotating quasi two-dimensional (2D) superfluid Bose gas [2]. A superfluid Bose-Einstein condensate is prepared in an oblate trap generated by dressing atoms placed in a quadrupole magnetic field with a radio-frequency field [3]. The atomic cloud is set in rotation by rotating a deformation of the trap [4]. The superfluid then hosts a triangular lattice of quantized vortices in a quasi-2D regime. The order of the lattice is progressively destroyed as the superfluid effective rotation rate increases. This situation enables to test if the scenario for the thermal melting of a 2D crystal proposed by Kosterlitz, Thouless, Halperin, Nelson and Young (KTHNY) is relevant for a vortex crystal in a quantum gas. The vortex lattice's translational and orientational order are characterized respectively by the pair correlation function and the angular correlation function, and we show that the evolution of these order functions with an effective temperature evidences a transition to a liquid state and is consistent with the KTHNY scenario involving the unbinding of 5-fold and 7-fold defects of the lattice. Interestingly, the melting temperature is three times lower than the estimated one in a pure BEC superfluid [5] This result paves the way to the understanding of the influence of temperature as a 2D quantum system reaches the Lowest Landau Level regime, which corresponds in our case to the situation when the effective rotation rate of the superfluid approaches the radial trapping frequency.

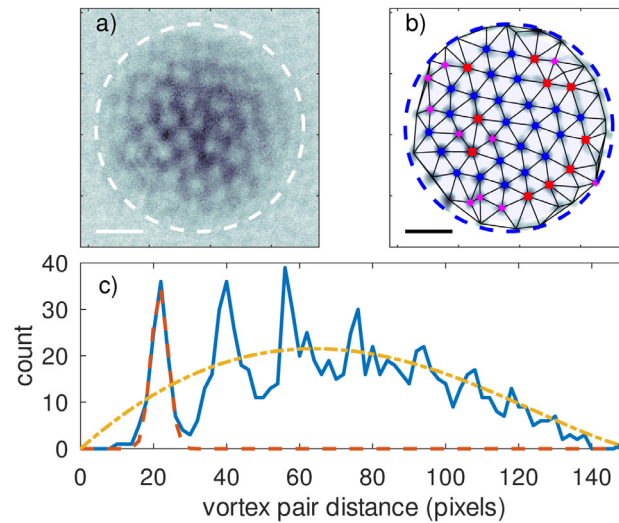


Fig. 1: a) experimental vortex lattice and b) reconstructed vortices positions with defects in red and pink. c) vortices pair distance histogram.

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Mon – 41

Ultrafast imaging of ytterbium tweezer arrays**Alessandro Muzi Falconi¹, Omar Abdel Karim^{3,4}, Riccardo Panza^{1,3}, Wenliang Liu³, Riccardo. Forti¹, Sara Sbernadori^{1,3}, M. Marinelli^{*1,2}, F. Scazza^{†1,3}**¹*Department of Physics, University of Trieste, Via Valerio 2, 34127 Trieste, Italy*²*CNR-IOM, Area Science park, 34139 Trieste, Italy*³*CNR-INO, Largo Enrico Fermi 6, 50125 Firenze, Italy*⁴*Department of Physics, University of Napoli, Via Cinthia 21, 80126 Napoli, Italy*

Detecting and manipulating individual atoms with high fidelity is essential for quantum simulation, metrology and, with even more stringent requirements, for quantum computing. I will present our recent results on ultrafast single-atom imaging, based on alternated pulses of highly saturated light addressing the broad $1S_0$ - $1P_1$ transition in ytterbium. With this scheme, we achieve in-trap single-atom detection fidelity and survival probability exceeding 99.8% within just few microseconds.

Beyond single-atom detection, we extend this ultrafast imaging scheme to the detection of multiple atoms in free space with single-particle resolution. By preparing and releasing multiply filled traps, we demonstrate single-atom-resolved detection without parity projection. This capability will enable new explorations of correlations and many-body dynamics in tweezer-trapped atomic ensembles.

Finally, will also mention the newest tweezer-based quantum platform under construction at the University of Trieste. This system integrates three key components: a quantum computing unit for executing arbitrary operations, a tweezer-cavity interface for cavity quantum electrodynamics and quantum networking experiments, and an atom reservoir to enable fast experimental cycle times and uninterrupted operations. This architecture will serve as a versatile testbed for advancing neutral atom quantum technologies.

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Magnifying the Performance of Quantum Thermal Heat Engine in the Vicinity of Exceptional Points

Mon – 42

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Quantum heat engines (QHE), meant to be counterparts to classical thermal machines, operate on quantum objects or systems that demonstrate quantum effects. Over the last decade, they have drawn significant attention due to their application in miniature and low-power systems, testing quantum thermodynamical limits and their role in biomolecular processes[1, 2]. QHEs have been implemented in the form of microscopic electro-mechanical systems[3] along with extremal forms such as single ions[4], quantum dots[1], or ultracold bosonic atoms[5].

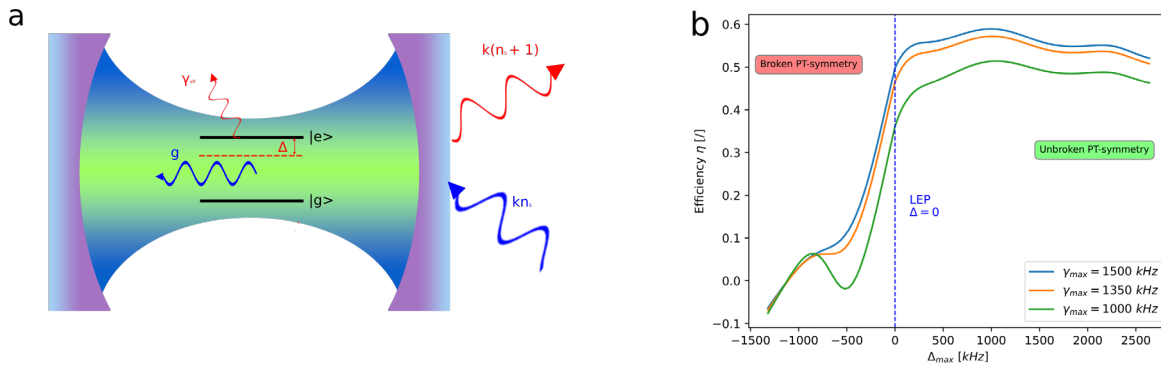


Fig. 1: (a) The model of quantum thermal heat engine. Two-level atom in an optical cavity. The cavity is in thermal contact with the photon reservoir. g – coupling strength between the atom and the cavity, κ – leakage rate of the cavity, γ_{eff} – effective dumping rate of the atom, Δ – detuning from the resonance between the frequency of the atom and the frequency of the cavity, n_s – the average number of photons in the cavity. (b) The efficiency of the QHE as a function of the Δ_{max} for different γ_{max} .

The effect of the Liouvillian Exceptional Points (LEP) on QHE performance has been studied over the past few years. It has been demonstrated that by encircling the LEP it is possible to enhance the performance of QHE realized with $^{40}\text{Ca}^+$ ion[4]. However, such QHE is pumped by a laser field described by the coherent state. Therefore, it shouldn't be considered the quantum analog of a classical thermal machine, which uses a chaotic heat bath as an energy source. In our presentation, we demonstrate the implementation of QHE described by the thermal states. Our model is shown in panel (a) of Fig. 1 and consists of a 2-level atom coupled with an optical cavity by the coupling strength g ; cavity losses are described by κ . Thermal photons are pumped from a photon reservoir. We implement the quantum Otto cycle by varying detuning from the resonance Δ and effective dumping rate γ_{eff} in time. As demonstrated in panel (b) of Fig. 1, a significant boost in the efficiency of a QHE is observed when the cycle encircles the LEP. Moreover, performance is enhanced by encircling more LEPs, which was realized by performing cycles for various γ_{max} . In conclusion, we show the possibility of exploiting the effects in the vicinity of EPs to improve the performance of QHE described by thermal states.

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Cavity-enhanced spectroscopy in the deep cryogenic regime- new hydrogen technologies for quantum sensing

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We demonstrate the first cavity-enhanced spectrometer fully operating in a deep cryogenic regime down to 4 K. Not only the sample but the entire cavity, including the mirrors and cavity length actuator [1], is uniformly cooled down ensuring the thermodynamic equilibrium of the gas sample. The setup is designed in a way that efficiently attenuates both external vibrations and those originating from the cryocooler itself ensuring stable operation of the optical cavity. High tunability of the wavelength is achieved by implementation of an optical parametric oscillator (OPO) pumped by the 1064 nm CW seed laser amplified to 10 W. This instrument opens the way to a variety of fundamental and practical applications [2].

We performed accurate Doppler-limited spectroscopy of the S(0) 1-0 line in molecular hydrogen covered by tuning range of the OPO idler beam. The transition energy was determined with accuracy at the level of 10^{-6} cm⁻¹. We demonstrate the first optical realization of three SI units in the challenging 4 - 20 K temperature regime: temperature (kelvin), amount of substance per unit volume (mole · meter⁻³) and pressure (pascal). We optically measured a part of the H₂ phase diagram covering over three orders of magnitude in pressure. This considerably improves the accuracy of the previous best $p(T)$ curve. Using optical methods, we also determined the conversion dynamics of the ortho-para H₂ isomers with high temporal resolution.

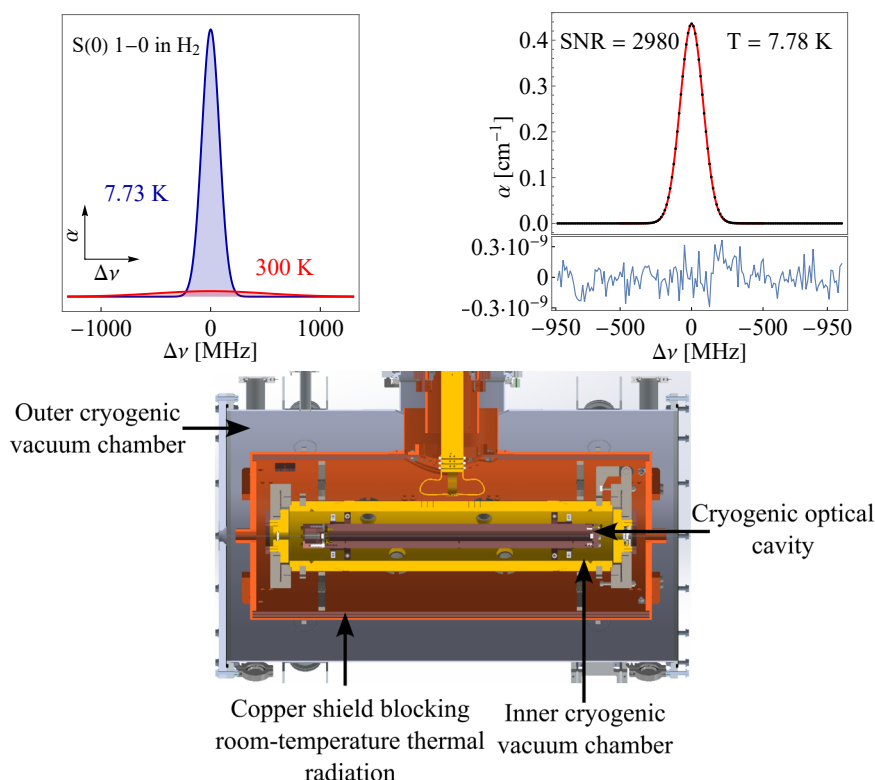


Fig. 1: A comparison of the S(0) 1-0 line in molecular hydrogen at 300 K and 7.73 K is showcased in the upper left corner, demonstrating the benefit of operating in cryogenic temperatures regime. A representative scan collected is showcased in upper right corner. The bottom panel showcases the design of the cavity operating in a vacuum chamber and capable of cooling all of its optical elements to temperature as low as 4 K.

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Antimony-based quantum dots as an alternative material platform for non-classical light sources operating at telecom wavelengths

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The security of data transmission in classical cryptography is based on the mathematical complexity. An alternative method of encryption is quantum cryptography. In this case, security is ensured by the fundamental laws of physics governing the microscopic world. Single photons can be used to encrypt cryptographic keys. To achieve this, efficient single-photon sources are required with low probability of multiphoton emission and high photon generation rate. For practical application, the source should emit photons in the 3rd telecom window, around 1.55 μm , which corresponds to minimum loss in common silica fibers. This ensures the longest possible distance for data transmission. The most promising physical system for generating single photons is epitaxial quantum dots (QDs). They offer outstanding quality of emitted single photons and the ability to achieve high generation rates with low probability of multiphoton events, along with compatibility with semiconductor technology. QDs emitting in the visible and near-infrared spectral ranges have reached a level of technological maturity that allows for nearly ideal single-photon sources. However, despite 20 years of research, it has not yet been possible to transfer these achievements to quantum dots emitting in the telecommunication spectral range.

We propose an alternative material system, not yet explored in this regard, namely (In)GaSb/AlGaSb QDs [1]. Main benefits of the GaSb-based system is emission at 1.55 μm , high refractive index and index contrast of Antimony-based materials important for photonic structures like microcavities and waveguides as well as compatibility with many material platforms, in particular enables direct growth on Si for scalable integration. Most beneficial method of QD growth, namely local nanohole droplet etching, has been transferred to this material system resulting in low spatial QD density on the order of $2 \times 10^7 \text{ cm}^{-2}$ (Fig. 1a) and low strain symmetric QDs of inverted geometry (Fig. 1c). The growth has been optimized to achieve very homogeneous QDs with inhomogeneous broadening below 10 meV (coloured boxes in Fig 3c). Indium composition determines the exact emission wavelength of the QDs emitting single photons over the entire 3rd telecom window [2]. The optical properties of these novel type of nanostructures has been determined by means of optical spectroscopy and the electronic structure has been describes using 8 band **k****p** method combined with configuration-interaction approach for excitonic states. Those revealed structure of higher energy states and importance of light hole states due to low biaxial strain in the QD volume. To optimize the performance of these QDs, the next step will be integration into photonic structures, e.g., nanoposts [3].

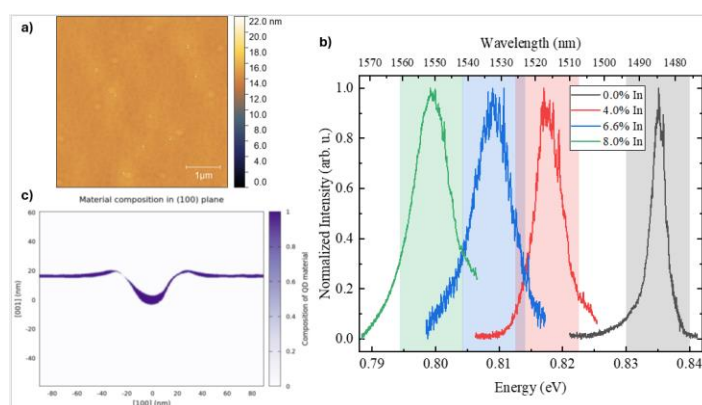


Fig. 1: a) AFM image of QD structure; b) emission spectra of QDs differing in In composition with 10 meV marked by coloured boxes; c) QD geometry based on AFM study used in the calculations

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Electrodynamics of vortices in quasi-two-dimensional scalar Bose-Einstein condensates

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An ensemble of static vortices in a nonrotating quasi-two-dimensional (2D) scalar Bose-Einstein condensate (BEC) without dissipation interact similarly to charged particles in a Coulomb gas [1], meaning their forces depend on the logarithm of their separation. For the nonrotating scalar BEC without dissipation, when the BEC number density is approximately constant, the motion of the vortex can be described according to the nonrelativistic dynamics of strings in 3D system [2], and the effective Maxwell's equations in a quasi-2D system [3]. This connection is valid for an inhomogeneous time-independent BEC number density in case of a nonrotating quasi-2D scalar BEC without dissipation [4].

In this study [5], we extend this connection to the inhomogeneous time-dependent quasi-2D scalar BEC, even with dissipation or rotation. By starting from the fundamental equations governing BEC, we show that vortex dynamics can be mapped onto Maxwell's equations as shown in Fig. 1.

$$\begin{aligned}
 \oint_{\partial\mathcal{M}} d\mathbf{l} \cdot \mathbf{v}_s(\mathbf{r}, t) &= \frac{2\pi\hbar}{M} \sum_{j=1}^{N_v(\mathcal{M};t)} q_j(t) \iff \oint_{\partial\mathcal{M}} (d\mathbf{l} \times \mathbf{e}_\perp) \cdot \mathbf{D}(\mathbf{r}, t) = \sum_{j=1}^{N_f(\mathcal{M};t)} Q_j(t) \\
 M \frac{\partial \mathbf{v}_s(\mathbf{r}, t)}{\partial t} &= \mathbf{f}_K(\mathbf{r}, t) - \nabla U_{\text{sf}}(\mathbf{r}, t) + \mathbf{F}_{\text{sf}}(\mathbf{r}, t) \iff \nabla \times \mathbf{H}(\mathbf{r}, t) = \mathbf{J}_f(\mathbf{r}, t) + \frac{\partial \mathbf{D}(\mathbf{r}, t)}{\partial t} \\
 \oint_{\partial\mathcal{M}} d\mathbf{l} \cdot \left[-\frac{U_{\text{sf}}(\mathbf{r}, t) - \bar{U}_{\text{sf}}(t)}{2\pi\hbar} \mathbf{e}_\perp \right] &= 0 \iff \oint_{\partial\mathcal{M}} (d\mathbf{l} \times \mathbf{e}_\perp) \cdot \mathbf{H}(\mathbf{r}, t) = 0 \\
 \int_{\mathcal{M}} d^2r \rho_v(\mathbf{r}, t) &= \sum_{j=1}^{N_v(\mathcal{M};t)} q_j(t) \iff \int_{\mathcal{M}} d^2r \rho_f(\mathbf{r}, t) = \sum_{j=1}^{N_f(\mathcal{M};t)} Q_j(t) \\
 \frac{\partial \rho_v(\mathbf{r}, t)}{\partial t} + \nabla \cdot \mathbf{J}_{\text{sf}}(\mathbf{r}, t) &= 0 \iff \frac{\partial \rho_f(\mathbf{r}, t)}{\partial t} + \nabla \cdot \mathbf{J}_f(\mathbf{r}, t) = 0 \\
 \mathbf{S}_{\text{sf}}(\mathbf{r}, t) &:= \mathbf{E}_{\text{sf}}(\mathbf{r}, t) \times \mathbf{H}_{\text{sf}}(\mathbf{r}, t) = \frac{M\mathbf{v}_P(\mathbf{r}, t)}{(2\pi\hbar)^2 \epsilon_{\text{sf}}} [U_{\text{sf}}(\mathbf{r}, t) - \bar{U}_{\text{sf}}(t)]
 \end{aligned}$$

Fig. 1: Duality between the vortices in the quasi-2D scalar BEC and the electrodynamics in the matter. On the left-hand side, $\mathbf{v}_s(\mathbf{r}, t)$ is the superfluid velocity, M is the mass of the BEC particle, $q_j(t)$ is the topological charge of the vortex (with index j) at time t , $N_v(\mathcal{M};t)$ is the number of vortices in the area $\mathcal{M}$ at time t , $\mathbf{f}_K(\mathbf{r}, t)$ is the effective kinetic force due to quantum potential, $U_{\text{sf}}(\mathbf{r}, t)$ is the effective potential due to the trap potential and density-density interaction, $\mathbf{F}_{\text{sf}}(\mathbf{r}, t)$ is the model-dependent additional force due to rotation, dissipation, etc., $\bar{U}_{\text{sf}}(t)$ is the spatial average of $U_{\text{sf}}(\mathbf{r}, t)$, and $\mathbf{e}_\perp$ is the unit vector perpendicular to the quasi-2D system. On the right-hand side, $\mathbf{D}(\mathbf{r}, t)$ is the electric displacement field, $\mathbf{H}(\mathbf{r}, t)$ is the magnetic field strength, $Q_j(t)$ is the free electric charge (with index j) at time t , and $\mathbf{J}_f(\mathbf{r}, t)$ is the free electric current density. In the final line, ϵ_{sf} is the effective vacuum permittivity and $\mathbf{v}_P(\mathbf{r}, t)$ is the velocity of the vortex core that is related to the effective polarization density $\mathbf{P}_{\text{sf}}(\mathbf{r}, t) := (M/2\pi\hbar) [\mathbf{v}_s(\mathbf{r}, t) - \mathbf{v}_P(\mathbf{r}, t)] \times \mathbf{e}_\perp$. For the derivation, see [5].

This duality provides a new way to understand and predict vortex behavior in the quasi-2D scalar BEC beyond the point-vortex model (e.g., damped point-vortex model [6, 7]), offering insights into complex fluid and quantum systems.

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Three-dimensional Bose-Fermi droplets at nonzero temperatures

Mon – 47

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We numerically study the formation of self-bound quantum Bose-Fermi droplets at nonzero temperatures. We have previously shown that such droplets can exist at zero temperature [1,2]. In this work the attractive atomic Bose-Fermi mixture is described in terms of quantum hydrodynamics, enriched by beyond mean-field corrections and thermal fluctuations, as well as by a simplified self-consistent Hartree-Fock model. Using the hydrodynamic description, we find low-temperature long-lived droplets in a free space, provided that the attraction between bosons and fermions is strong enough. On the other hand, a simplified Hartree-Fock treatment supports the existence of Bose-Fermi droplets in equilibrium with the gas of thermal bosons and fermions, with the Bose-Einstein condensate itself being completely hidden inside a droplet. Both thermal and non-thermal droplets can be used to simulate astrophysical phenomena such as disruption of a white dwarf star by a black hole [3,4].

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Mon – 49

Enhancing charging of a quantum battery using directional quantum jumps

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There is an increasing interest in research of quantum energy storage systems, known as quantum batteries (QBs) [1,2]. QBs are described as n -dimensional quantum systems with non-degenerate energy levels from which work can be reversibly extracted and energy can be reversibly deposited using cyclic unitary operations [3]. Quantum batteries have received a lot of attention because their charging time decreases with their capacity. One of the most crucial issues in QB design is optimizing the battery's charging process. Dissipation, a negative phenomenon that exists in all physical systems, must be considered during the optimization process.

Here we explore a potential of directional quantum jumps for improving QB's charging process. We present a system in which quantum jumps can improve charging time and charge level [4]. A two-stage charging protocol has been developed to achieve very good results for battery time and charge level while maintaining optimal and realistic parameters. The scheme we propose should be feasible experimentally.

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Mon – 50

Phase diagram of interacting Cat qubits

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Dynamically protected cat qubits[1] are realized through a coherent two-body drive and incoherent two-body loss. The dynamics inherits a strong parity symmetry which implies a symmetry between classical and quantum field. We show that the mean field phase diagram exhibits a second order phase transition where both modes go to zero and an additional first order transition. For vanishing Kerr non-linearity, there is an exceptional point where the first order transition becomes second order.

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Poster session

Tuesday



Poster sessions

Tuesday



Sympathetically Cooling the Motion of a Nanoparticle in a Paul Trap using a Co-Trapped Ion

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Creating quantum motional states of massive mechanical systems is the key to testing the quantum-to-classical transition in micrometer-scale systems, exploring quantum gravity and dark matter, as well as building quantum transducers and high-fidelity sensors [1-7]. Levitated optomechanics (levitodynamics) offers an ideal platform for creating quantum motional states as the center-of-mass (COM) mode of a levitated nanoparticle is not clamped and can be manipulated optically on demand, including dynamical tuning of the trapping potential [8]. To create a quantum state of a mechanical system, we first need to cool the mechanical mode to its quantum ground state. Recently, cooling of the COM mode of a levitated nanoparticle to the quantum ground state was demonstrated [9]. However, creating a state with a negative Wigner function, a signature of non-classicality achieved in alternative large mechanical resonators [3,4], remains an open challenge in levitodynamics. The main obstacle to this goal is the fast decoherence of mechanical modes due to scattering of light from the trapping lasers. To solve this problem, recent experiments have achieved the co-trapping of an electrically charged nanoparticle alongside multiple ions in a Paul ion trap without the use of trapping lasers [10], which reduces the decoherence and enables us to exploit tools from ion physics in levitodynamics. However, a theoretical toolbox for such systems is yet to be developed.

In this work, we develop a full quantum theory for a system of multiple ions and nanoparticles co-trapped in a dual-frequency Paul trap. We employ it to study the potential of Doppler-cooled ions to sympathetically cool the COM mode of the nanoparticle. We compute cooling dynamics using the parameters of state-of-the-art experiments [10] and also derive performance bounds (such as the cooling limit) in arbitrary traps. We derive an analytical expression for the steady-state temperature of the COM mode starting from the quantum master equation, which reveals the non-trivial scaling of the steady-state temperature with nanoparticle charge and mass. Further, we numerically solve the full quantum dynamics of the nanoparticle and ion in a dual-frequency Paul trap and compute the contribution of micromotion to the steady-state energy of the nanoparticle COM mode. Finally, we compute stable 3-D configurations of multiple ions and a nanoparticle in the same Paul trap and calculate the modified trapping frequencies and couplings between different motional modes. We predict an enhancement in cooling of the particle COM mode by using more than one ion, which saturates for a large number of ions. Our theory paves the way for the realization of ground state cooling of the COM motion using additional tools from ion physics and optomechanics, such as including an optical cavity.

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Increasing the key generation rate in realistic discrete-variable QKD based on SPDC source by utilizing WDM modules.

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Although quantum key distribution (QKD) theoretically offers great security improvement over classical encoding methods, practical imperfections in its implementation significantly limit its performance, especially in terms of key generation rate. Recently Pseiner et al. [1] experimentally demonstrated the possibility to significantly increase this quantity by utilizing wavelength division multiplexing (WDM) technology. However, despite promising experimental results, a detailed theoretical treatment of the aforementioned scenario is still missing.

In this work, we theoretically investigate the possibility of increasing the key rate produced with the entanglement-based version of the BB84 protocol. We consider a modification of the traditional entanglement-based QKD setup in which Alice and Bob own WDM modules and each WDM output channel leads to separate detection system as shown in Fig.1. The idea is to send the pairs of spectrally correlated photons with different frequencies into separate pairs of WDM channels in order to generate several keys in parallel and later merge them together. If the spectral correlation between the photons belonging to the same SPDC pair is relatively strong it can be possible to define multiple pairs of correlated systems to which these photons could go with very high probability.

We analyze both the cases of SPDC source producing strongly negative and strongly positive spectral correlation between the pairs of generated photons. In order to properly assess the potential advantage, we numerically optimize the parameters of the SPDC source, including the effective-phase matching function (EPMF) width of the nonlinear crystal, and the duration and intensity of the pump laser pulses, for various numbers of WDM channel pairs utilized by the trusted parties. We analyze both the cases of SPDC source producing strongly negative and strongly positive spectral correlation between the pairs of generated photons, showing how modifying the aforementioned quantities can impact the overall key generation rate. We compare the results with the maximal key generation rate that can be obtained in traditional setup configuration, without WDM modules. Furthermore, we study the influence of WDM channels width, separation and transmission profile on the outcomes of our analysis. While the majority of the calculation is performed for the noiseless case, we also study the impact of imperfect detection on the total key generation rate.

The detailed results of our work are presented in Ref.[2]

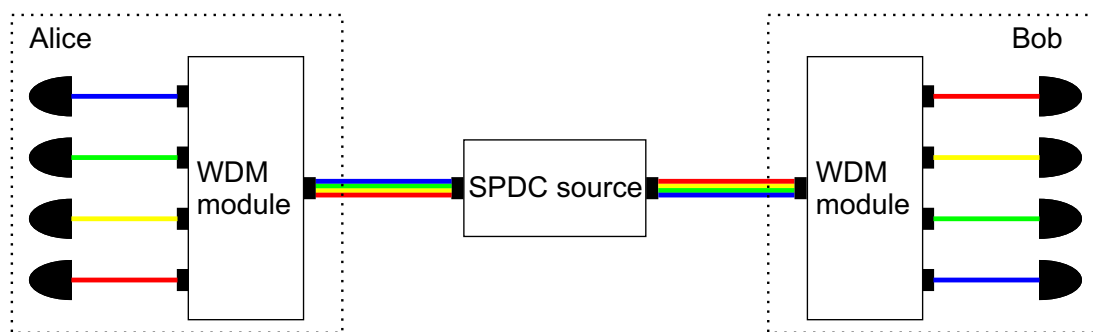


Fig. 1: Schematic diagram of the considered setup

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Effective light-induced Hamiltonian for an atom with a large nuclear spin

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Ultra-cold fermionic atoms with two valence electrons have a unique internal state structure, as the nuclear spin is decoupled from the electronic degrees of freedom in the ground electronic state. The nuclear spin states are thus well isolated from the environment and can be used as a platform convenient for quantum computation and quantum simulation [1, 2]. A coupling with off-resonance light is an essential tool to selectively and coherently manipulate the nuclear spin states. Although light shifts in alkaline-earth-like atoms have been expressed in terms of the Clebsch-Gordan coefficients [3], these equations are complex to analyze and require numerical calculation.

In this work, we present a systematic derivation of the effective Hamiltonian for ultra-cold fermionic atoms with two valence electrons due to such an off-resonance light. We obtain compact expressions for the scalar, vector and tensor light shifts $\bar{b}_0$, $\bar{b}_1$ and $\bar{b}_2$, taking into account both linear and quadratic contributions to the hyperfine splitting. The analysis has been carried out using the Green operator approach and solving the corresponding Dyson equation. Finally, we analyze different scenarios of light configurations which lead to the vector- and tensor-light shifts, as well as the pure spin-orbit coupling for the nuclear spin.

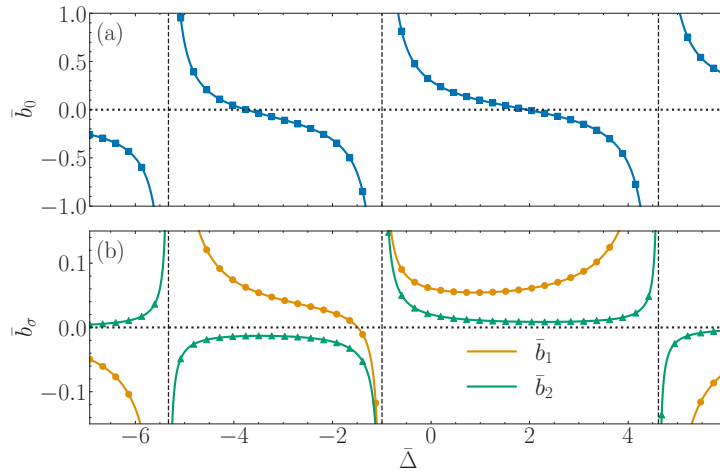


Fig. 1: Dependence on the dimensionless detuning $\bar{\Delta} = \Delta/(\hbar A_{\text{HF}})$ of (a) the dimensionless scalar coefficient $\bar{b}_0$, as well as (b) the vector $\bar{b}_1$ and tensor $\bar{b}_2$ coefficients entering the effective Hamiltonian. The values of nuclear spin $I = 9/2$ and quadratic shift $\gamma = 0.006$ are taken for ^{87}Sr atoms. Clebsch-Gordan calculations are marked by solid lines, while squares, circles and triangles represent our analytical results, respectively.

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Towards a Quantum Processor with programmable connectivity and non-local interactions

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Quantum computers and simulators are especially promising for tackling problems that require a high degree of entanglement. However, the efficient and deterministic generation of many-body entanglement still poses a challenge. We report on progress towards building a quantum processor based on an array of single atoms trapped in optical tweezers and strongly coupled to a high-finesse fiber cavity. The cavity enables non-local interactions, mediated by the joint coupling of the atoms to the cavity mode. Microscopic addressing via the optical tweezers allows for tuning this coupling for each atom, enabling programmable connectivity. This, combined with other established techniques in cavity quantum information processing, provides us with an extensive experimental toolkit for generating many-body entanglement and a variety of quantum computation and simulation experiments.



Towards quantum optomechanics with a levitated nanoparticle in a Paul trap

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Levitated mechanical oscillators represent a promising platform for bringing optomechanical experiments into the quantum regime [1]. Several challenges remain before quantum control of these objects is achieved. For a nanoparticle in a Paul trap, already shown to have an ultra-high quality factor [2], a key milestone would be to cool to the quantum ground state, as has been observed in optical traps [3]. In order to achieve ground-state cooling, a clear understanding of the mechanisms opposing cooling is required. Furthermore, the nanoparticle in ultra-high vacuum has been successfully co-trapped with an atomic ion [4]. Here I will present recent results on characterising nanoparticle heating rates, as well as an overview of our hybrid qubit-nanoparticle system.

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Partial distinguishability in the interference of Gaussian states in linear unitary networks

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Partial distinguishability of photons is a fundamental aspect of quantum interference and a major source of noise in any photonic quantum information protocols, as it degrades multi-photon interference and alters the output photon statistics. It originates from the imperfect overlap of the internal states of the photons, such as time delay, polarization, and spectral profile. In two-photon interference, this effect was first demonstrated in the Hong–Ou–Mandel experiment, where two single photons impinging on a beam splitter exhibit perfect quantum interference, resulting in zero coincidences only when the photons were fully indistinguishable [1].

Consider two photons, each prepared with an internal state $|\psi_k\rangle$, interfering at a balanced beam splitter. The probability of detecting one photon in each output port (a coincidence event) is

$$p(1, 1) = \frac{1}{2} (1 - |\langle\psi_1|\psi_2\rangle|^2), \quad (1)$$

which vanishes when the two photons are indistinguishable, i.e., when their internal states have complete overlap, $\langle\psi_1|\psi_2\rangle = 1$. Then, a deviation from perfect indistinguishability degrades this destructive interference. As shown in Eq. (1), in two-photon interference, the partial distinguishability affects the photon statistics only in function of the modulus of the inner product between their internal states. When three or more photons interfere, the phenomenon exhibits a richer behavior, with the complex phase of the inner product also affecting the photon statistics, as shown in recent experimental results. [2,3].

However, the influence of partial distinguishability in the interference of Gaussian states has not yet been fully explored. In addition, recent works have shown the significant potential of the Gaussian Boson Sampling, which employs single-mode squeezed states as inputs and for which this constitutes an important source of noise [4,5]. In this work, we quantify the effect of partial distinguishability in the interference of single-mode squeezed states through its explicit dependence in the internal state parameters [6]. In the simple model where the photons have a homogeneous overlap, the effect of distinguishability emerges as an effective thermal state contribution. Beyond being a fundamental step towards understanding Gaussian-state interference, this analysis also allows for the examination of noise effects arising from partial distinguishability in the Gaussian Boson Sampling scheme.

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Linearized Stochastic Projected Gross-Pitaevskii Equation: Equilibrium and Equilibration of Bose-Einstein Condensates

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We present a thorough analysis of the linearized stochastic projected Gross-Pitaevskii equation (SPGPE) describing finite temperature in Bose-Einstein condensates (BECs). A study of its equilibrium properties reveals an optimal choice for the cut-off that divides the Bose gas into a low energetic coherent region forming a classical wave and a high energetic thermal cloud acting as a reservoir. The linearized SPGPE equilibration properties highlight the relevance of energy damping, the number conserving scattering between thermal and coherent atoms. It is demonstrated to dominate relaxation and notably also condensate growth, thereby questioning the validity of its neglect in the commonly employed simple-growth SPGPE. Hence, our work suggests the need for a re-examination of decay processes in BECs studied under the neglect of energy damping. Simulations of the full SPGPE back up the presented results and extend our arguments beyond the linear regime.

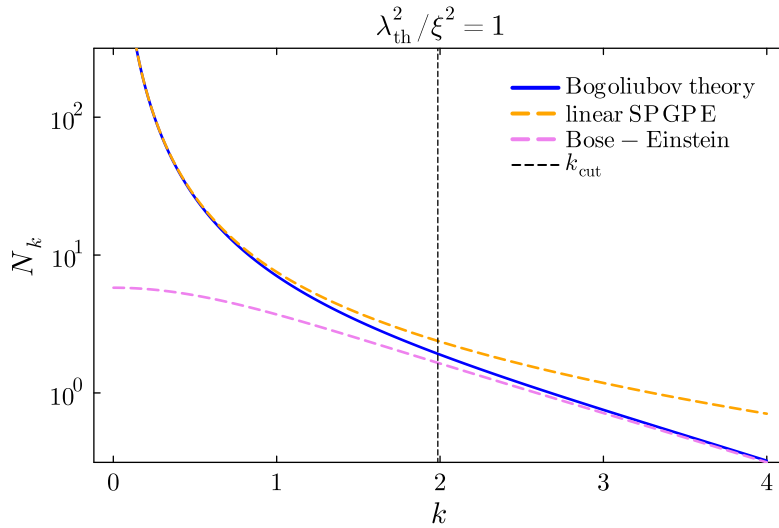


Fig. 1: Occupation number according to the linearized SPGPE (orange dashed line) and the Bose-Einstein distribution (violet dashed line) compared to the Bogoliubov predictions (solid blue line). The black dashed line highlights the suggested cut-off: SPGPE treatment corresponds to an occupation number according to the orange dashed line to its left (for smaller k) and to the violet dashed line to its right (for larger k).

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Optical atomic clock without a frequency comb

Tue – 8

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The advanced optical atomic clocks (OAC) [1] are based on two detection schemes: Ramsey fringes [2] and fluorescence [3] measurements from two-photon excitation. The sensitivity of both the schemes is limited to $1/\sqrt{N}$, where N represents the number of atoms for Ramsey fringes and fluorescent photons for fluorescence measurement. In this work, we propose a new detection scheme for calibrating two frequencies simultaneously based on phase measurement using a dual Mach-Zehnder interferometer with a cesium vapor cell in a double lambda atomic configuration as shown in Fig. 1. The sensitivity of this method is limited to $1/\sqrt{N}$, where N represents the number of photons. Using Cesium D1 transition, the standard quantum-limited sensitivity and stability of the OAC are estimated as $4.59 \sqrt{\text{Hz}}$ and $2.18 \times 10^{-15} \sqrt{\text{Hz}^{-1}}$, respectively, at 347 K temperature, which is two orders of magnitude better than existing vapor cell OAC. The effect of Doppler broadening is reduced by choosing the double lambda atomic scheme with co-propagating lasers. The study of laser phase noise shows that the clock is robust against the laser linewidth of less than 10 KHz. A linewidth of 100 KHz degrades the clock stability from $\approx 1.7 \times 10^{-15} \sqrt{\text{Hz}^{-1}}$ to $2.2 \times 10^{-15} \sqrt{\text{Hz}^{-1}}$ at a temperature range of 300 K to 360 K. The two simultaneously calibrated frequencies are mixed to create a beat frequency at radio wave signal can avoid the need of a frequency comb, which improves the portability of the OAC.

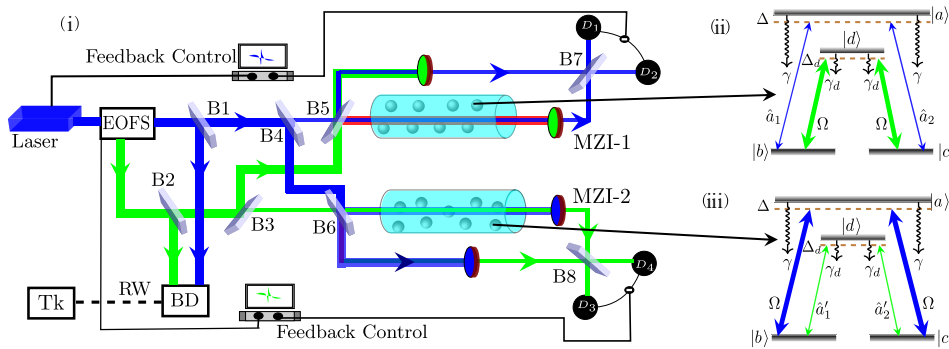


Fig. 1: (i) Schematics of the optical atomic clock. Green cylinder: vapor cell containing cesium atoms in double lambda configuration. EOFS : electro-optical frequency shifter, BD: heterodyne beat detector, B_i ($i = 1, 2, \dots, 8$): 50:50 beam-splitter, Tk : Timekeeping, D_i ($i = 1, 2, 3, 4$): photo detectors, RW: radio-wave, MZI: Mach-Zehnder interferometer. (ii), (iii) Energy diagram for a four-level system in double lambda configuration with energy level $|j\rangle$, $j = a, b, c, d$, and energy $\hbar\omega_j$, where $\hbar$ is the reduced Planck constant and ω_j is frequency. $\omega_a > \omega_d > \omega_b = \omega_c$. $|b\rangle - |c\rangle$ and $|a\rangle - |d\rangle$ transitions are dipole forbidden. The population decay rate of $|d\rangle$ to $|b\rangle$ and $|d\rangle$ to $|c\rangle$ is $2\gamma_d$, and the population decay rate of $|a\rangle$ to $|b\rangle$ and $|a\rangle$ to $|c\rangle$ is 2γ . Two strong classical fields with equal Rabi frequency Ω and mutually orthogonal polarization drive $|b\rangle - |d\rangle$ and $|c\rangle - |d\rangle$ transitions in (ii) and $|b\rangle - |a\rangle$ and $|c\rangle - |a\rangle$ transitions in (iii). The transitions $|b\rangle - |a\rangle$ and $|c\rangle - |a\rangle$ in (ii) and $|b\rangle - |d\rangle$ and $|c\rangle - |d\rangle$ transitions in (iii) are coupled to two weak quantum fields with mutually orthogonal polarisation represented with annihilation operators $\hat{a}_1, \hat{a}_2$ and $\hat{a}'_1, \hat{a}'_2$, respectively. Δ, Δ_d : detuning of the laser from atomic transition frequency. Whenever the laser frequencies are detuned from the atomic resonance frequencies by same amount (i.e., $\Delta = \Delta_d \ll \gamma$), a non-zero phase is added to the output field from the atomic scheme. This additional phase shifts the interference fringes, which is used as feedback.

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Observing mode coalescence in a driven-dissipative quantum many-body system

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In recent years, ultra-cold atom research has driven significant advancements in quantum optics, condensed matter physics, and quantum information processing, leading to the discovery of novel states of matter and new quantum simulation platforms. While many studies have focused on weakly interacting, short-range systems, there is a growing interest in systems with long-range interactions, especially those involving dissipation, which can give rise to complex dynamics. Understanding such systems can reveal new quantum phenomena and provide deeper insights into open-system dynamics. Our experiment investigates the collective phenomena of a Bose-Einstein Condensate (BEC) of rubidium atoms trapped in a high-finesse cavity and driven by a dispersively detuned pump laser. The coupling between the BEC and the cavity induces long-range interactions, resulting in two roton-like excitation modes corresponding to two exotic superradiant phases [1]. The tunability of our system allows us to examine a parameter regime where the energy of two modes would cross in a closed system. However, the inherent dissipation makes their fate less trivial and causes the coalescence of these two modes in energy. In this regime, the system acquires an effectively imaginary energy component, resulting in gain and loss states. This leads to dissipation-induced dynamical instability in the system [2]. By performing cavity Bragg spectroscopy we can observe the coalescing modes and reveal a chiral response of the system in this region.

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Leveraging high-dimensional entanglement to boost the success probability of linear-optical fusions

Tue – 10

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Photonic qubits play a crucial role in quantum communication and computation. However, their entangling operations using linear optics and photon detectors are known to be inevitably probabilistic. In particular, a Bell-state measurement, also called type-II fusion gate, succeeds with a probability up to 50%, which makes many applications, such as linear-optical quantum computation and repeaters, inefficient. In this work [1], we present a way to effectively increase the success probability of a fusion gate using photonic *qudits*. A photonic qudit of dimension d is defined with a photon and d modes, and thereby its dimension can be increased without increasing the number of photons. We introduce a new quantum measurement on two qudits, called pairwise fusion gate (PFG). In contrast to the fusion gate on qubits being a probabilistic projection onto a Bell state, the PFG is a probabilistic projection onto a “pairwise” Bell state, $\frac{1}{\sqrt{2}}(|i\rangle|j\rangle \pm |j\rangle|i\rangle)$ or $\frac{1}{\sqrt{2}}(|i\rangle|i\rangle \pm |j\rangle|j\rangle)$, which is a Bell state defined on a two-qubit subspace of two qudits, specified by two integers $i, j \in \{0, 1, \dots, d-1\}$. The PFG can be implemented with the setup shown in Fig. 1 for time-bin qudits with the success probability of $1 - d^{-1}$, which exceeds the upper limit of 50% on the standard fusion gate. Although it is not clear whether the PFG can be used as a substitute for the standard fusion gate, we find that entanglement swapping can be implemented with PFGs instead of standard fusion gates, where the success probability is boosted from 50% to $1 - d^{-1}$. We also show that this entanglement swapping can be applied to a quantum repeater protocol using three-qudit photonic GHZ states and quantum memories. This protocol outperforms the protocol that uses the standard fusion gates thanks to the boosted success probability. This work presents a novel application of photonic qudits that successfully circumvent the fundamental limitation of photonic quantum information processing, distinct from their conventional use case as high-capacity information carriers.

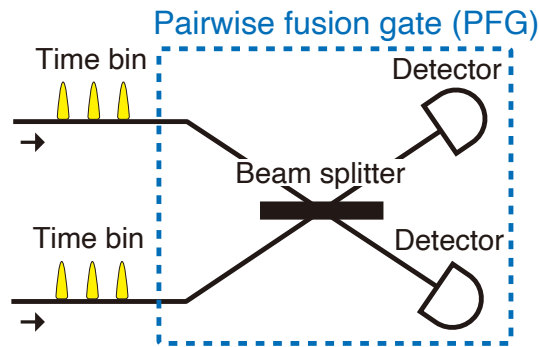


Fig. 1: Linear-optical circuit of a pairwise fusion gate for time-bin qudits.

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Large associative ionization cross-section for low lying states of Li

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We observe a high formation rate of Li_2^+ ions via resonant excitation of ^7Li [Fig 1.a] atoms to low-lying 2P and 3S states. This phenomenon was observed in a dilute Magneto-optical trap (MOT) (average atomic separation $\approx 10 \mu\text{m}$, $T \approx 500 \mu\text{K}$) of ^7Li formed at the center of a co-operational ion trap [Fig 1.b]. The overlaps in the Potential Energy Curves (PECs) of neutral Li_2 and the Li_2^+ , together with the quadratic dependence of Li_2^+ formation rate on the density of MOT, point towards associative ionization (AI) as the formation pathway [1]. We use the Parametric Excitation technique to not only identify these ions as Li_2^+ but also decipher the entire chain reaction :



We use the ion trap to confine these molecular ions and study their photo-dissociation (PD) in the presence of MOT light [Fig 1.c]. Unlike the case of Rb_2^+ [2], we observe a few long-lived Li_2^+ in the ion trap, even in the presence of the MOT light. These ions are formed in the lower vibrational states of the $X^2\Sigma_g^+$ PEC which have low PD rates towards the dissociation continuum of the lowest $^2\Sigma_u^+$ state for the 670nm wavelength allowing the Li_2^+ to be co-trapped with the Li MOT. It is interesting to note that the MOT light of other species, such as Rb (780 nm), Cs (852 nm), and K (767 nm), has lower frequencies than the Li MOT, which presents an opportunity to co-trap Li_2^+ with these species for further cold chemistry studies. In addition, we observe a fast conversion of ($\approx 50\%$) of Li_2^+ to Li^+ in the absence of MOT light (and the MOT atoms), which needs further investigation.

The significant AI rate of Li_2^+ suggests a large cross-section for this process. We carried out measurements to determine the AI cross-section to be very high ($\approx \pi (1000 a_0)^2$) [3]. This is interesting, despite the fact that the participating atoms [$\text{Li}(2\text{P})$ & $\text{Li}(3\text{S})$] are not in high-lying Rydberg states [4].

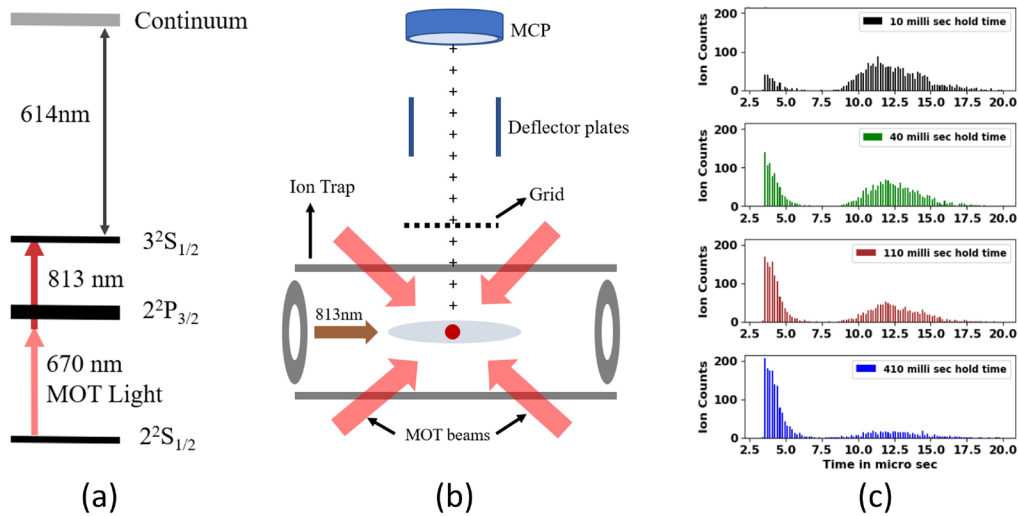


Fig. 1: a) Li atomic states with MOT transition, 813 nm, ionization continuum b) The experimental construct showing the MOT beams and the MOT formed at the center of the ion trap, the radial extraction scheme. c) The evolution of the time of flight spectrum of the ions extracted onto the microchannel plate (MCP) in the presence of MOT. The ions at times of arrival (3-7.5 μsec) are Li^+ and the rest are Li_2^+ .

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Structural transitions and stochastic dynamics of Coulomb clusters

Tue – 12

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Coulomb crystals are spatially ordered structures that emerge from sufficiently damping a system of co-trapped like-charges. As the particles lose kinetic energy, they self-organize into configurations where the confinement force balances the mutual Coulomb repulsion. Linear chains of optically active trapped ions have been instrumental in developing modern quantum technologies toward precision spectroscopy and quantum information processing [1-2]. Due to the precise control over the system's parameters, they provide an exceptional platform for investigating collective phenomena across various scales, as the crystal can be built atom by atom [3].

We present structural transitions observed in clusters formed by a few laser-cooled atomic ions confined in a 3D trap. Numerical analysis of the clusters' vibrational modes reveals distinct lattice dynamics at specific transition points, and the corresponding signatures are observed experimentally. Our experiments and analysis of Coulomb cluster structures show that this small system emulates different kinds of solid-solid structural transformations, where lattice instability or metastability determines the nature of a structural phase transition.

In addition, we identify a few clusters with two symmetric configurations of degenerate energies. In real time, the ions reorient as the entire cluster switches between the two potential energy minima. To understand the mechanism behind such stochastic switches and their rate, we apply methods from quantum chemistry [4] and reaction rate theory [5]. The theoretical predictions agree well with stochastic-dynamics simulations and experimental observations, pointing towards a thermal-activation process due to the photon bath used for Doppler-cooling of the cluster. Such studies can be performed in the quantum regime by cooling the entire cluster to the motional ground state.

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Experimental noiseless quantum amplification of coherent states of light by two-photon addition and subtraction

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Controlled addition and subtraction of single photons represent crucial tasks of quantum state engineering and fundamental building blocks of nonlinear photonic devices. Here, we report on the experimental implementation of a noiseless quantum amplifier for coherent states of light that is based on the conditional addition of two photons followed by the conditional subtraction of two photons. [1] We comprehensively characterize the noiselessly amplified coherent states via quantum state tomography, and analyze the amplification gain and noise properties of the amplifier. Examples of Wigner functions of the conditionally generated noiselessly amplified coherent states are shown in Fig. 1. We observe very good agreement between the experiment and theoretical predictions. We show that the performance of our noiseless amplifier is essentially the same as the performance of an interferometric scheme, where the signal is split into two modes, each mode is noiselessly amplified, and the modes are interferometrically recombined. Sequences of multiple photon additions and subtractions thus represent an efficient and experimentally feasible alternative to multiplexing that was originally proposed to boost the performance of noiseless quantum amplifiers. Beyond noiseless quantum amplification, our experiment represents a significant step forward towards engineering complex quantum operations on traveling light beams by coherent combinations of various sequences of multiphoton additions and subtractions.

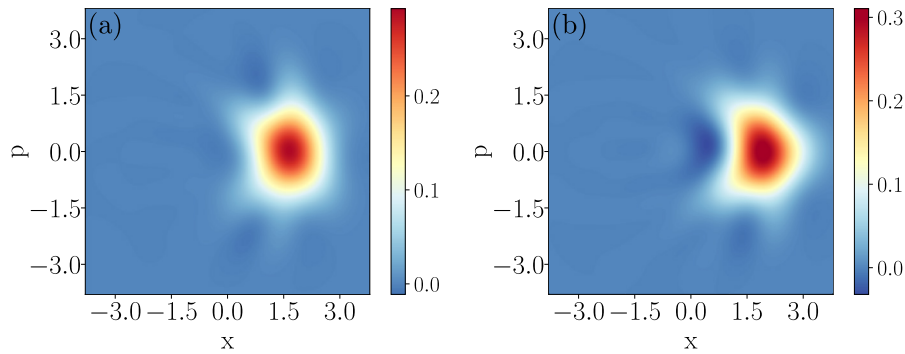


Fig. 1: Experimental Wigner functions of noiselessly amplified coherent state with input amplitude $\alpha = 0.77$. Results are shown for amplification by operations $\hat{a}\hat{a}^\dagger$ (a) and $\hat{a}^2\hat{a}^{\dagger 2}$ (b).

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Spatially resolved temperature measurements on ultra-cold atoms using Rydberg Doppler broadening spectroscopy

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We introduce a technique for spatially resolved temperature measurement utilizing Rydberg Doppler broadening thermometry. This method employs two laser beams (420 nm and 1012 nm) arranged perpendicularly to excite laser-cooled Rb-87 atoms from the ground state ($5S_{1/2}$) to the Rydberg state ($70S_{1/2}$) via an intermediate state ($6P_{3/2}$). The perpendicular configuration allows for selective probing of specific positions within the atom cloud, enabling localized temperature measurements [1]. This technique offers the potential for nanokelvin resolution, attributed to the exceptionally narrow natural linewidth ($2\pi \times 0.95$ kHz) of the involved Rydberg transition line. We have also measured the temperature of an atomic sample after heating it with resonant laser light (see Figure 1)).

Furthermore, this approach enables the analysis of position-momentum correlations within the cold atom ensemble. Momentum information is extracted via the Doppler shift, while spatial information is inferred from the arrival time of ions detected by a channel electron multiplier with a spatial resolution of $20\mu m$. To induce correlations, we first heat the atomic cloud with resonant laser light and then allow it to freely expand. During this time-of-flight (TOF), the atoms develop position-momentum correlations (Figure 2).

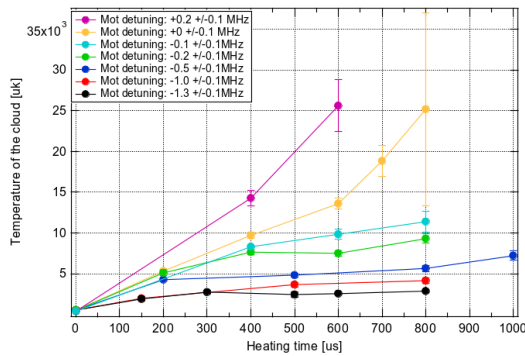


Fig. 1: Measured temperature as a function of heating time

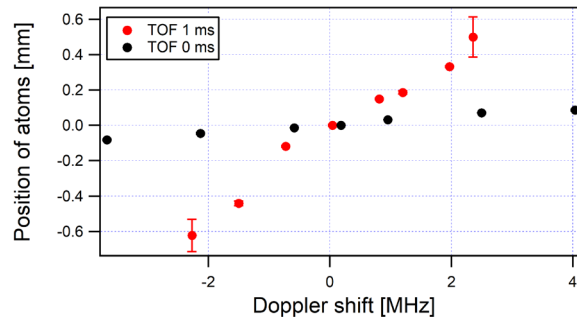


Fig. 2: Position-momentum correlations after 1 ms of free expansion of the atomic cloud.

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Entanglement of massive, charged objects via a lossy conductive wire**L. Papa^{*1}, C. Gonzalez-Ballester**¹Institute for Theoretical Physics, TU Wien, Wiedner Hauptstrasse 8-10/E136, 1040 Vienna, Austria

Bringing ever larger masses into quantum states not only benchmarks the amount of achievable quantum control and sensitivity of mechanical sensors, but also provides a pathway towards exploring untested physics like exotic particles or quantum gravity. While Optomechanics experiments like the generation of Schrödinger cat states [1] and entanglement of picogram drums [2] represent huge achievements in this pursuit, their scalability in terms of both mass and wave function expansion is limited quite simply by their material connection to the environment as a source of decoherence. Eliminating or minimizing this connection, with e.g. optically levitated nanoparticles [3] or milligram torsion pendula [4] should in principle yield higher environmental isolation with simultaneously higher degree of motional control. Since optically mediated entanglement is predicted to be fundamentally challenging for these systems [5], most efforts to generate macroscopic motional entanglement are focused on utilizing the Coulomb interaction which is relatively short-ranged ($\propto 1/r^3$).

In this work, we propose to use a conductive wire as a mediator of the particle-particle Coulomb interaction. This has been shown to enhance quantum protocols in the past [6]. Here, we are fully characterizing the effect of the wire with regards to extended range, tunability of the resulting force and added decoherence. We quantize the electromagnetic field in the presence of the lossy wire utilizing the formalism of macroscopic quantum electrodynamics [7]. Decoherence and coupling rates are extracted from a Born-Markov master equation and expressed in terms of the classical Green's function. Our treatment uncovers an unconventional coherent squeezing rate in the modified Hamiltonian, which enhances the entanglement generation and which counterintuitively increases with the resistance of the wire. We verify the extended range of the interaction using the Green's function for an infinitely extended wire and we determine parameter regimes in which entanglement can be experimentally observed for levitated nanoparticles, as well as milligram-scale torsion pendula.

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Conversion of correlations in quantum bosonic networks

Tue – 16

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Intermodal correlations play a crucial role in operation of quantum networks and quantum computers. Particular attention has been directed to the continuous variable systems which are widely used because of their experimental availability and controllability [1]. The key quantities in operation of quantum networks composed of coupled bosonic modes, described by creation (annihilation) operators $a_i^\dagger$ (a_i), are single ($i = j$) and two-mode ($i \neq j$) correlation functions $\langle a_i a_j \rangle$ and $\langle a_i^\dagger a_j \rangle$. A non-zero single mode correlation function $\langle a_i a_i \rangle$ is a measure of single-mode two-photon coherence, which leads to squeezing of the field fluctuations in the mode i . The two-mode correlation function $\langle a_i^\dagger a_j \rangle$ is a measure of the one-photon or the first-order coherence of the fields in the two modes which is instrumental in the continuous variable quantum computing, whereas the two-photon correlation function $\langle a_i a_j \rangle$ is a measure of multimode squeezing of the correlated modes which is necessary for entanglement of the modes [2,3].

In this presentation we demonstrate how the inter-mode correlations can be generated between two bosonic modes mutually coupled through two fundamentally dissimilar physical interaction processes, the linear photon exchange type interaction and the nonlinear parametric type interaction. The parametric interaction is well known that it amplifies populations of the modes whereas the linear interaction transfers photons between the modes. In addition, parametric interaction can entangle modes being in classical states, and the linear interaction is known to generate entanglement only if the modes are in nonclassical states [4].

We have derived analytical expressions for the correlation functions which show that there exists a simple relation between varying the intra-mode populations and fluctuations and the creation of the inter-mode correlations, that it is possible to measure the inter-mode one- and two-photon correlation functions by readout of the populations or the variances of the field quadratures. In the evaluation of the correlation functions we include decoherence (damping with rate κ) expected for modes interacting with their environments and assume that initially the modes are in single-mode squeezed states determined by numbers of photons n_1, n_2 and degrees of the internal two-photon correlations, $\langle a_1 a_1 \rangle = m_1$ and $\langle a_2 a_2 \rangle = m_2$. For example, the one- and two-photon correlations under the linear interaction are

$$\langle a_1^\dagger a_2 \rangle = -\Delta n \sin \psi \cos \psi = \frac{1}{2} \frac{\partial}{\partial g} (\Delta n \cos^2 \psi) = \frac{1}{2} \frac{\partial}{\partial g} (\langle a_1^\dagger a_1 \rangle - \langle a_2^\dagger a_2 \rangle) \quad (1)$$

$$\langle a_1 a_2 \rangle = -m \sin \phi \sin \psi \cos \psi = \frac{1}{2} \frac{\partial}{\partial g} (m \sin \phi \cos^2 \psi) = \frac{1}{2} \frac{\partial}{\partial g} (\langle a_1 a_1 \rangle + \langle a_2 a_2 \rangle) \quad (2)$$

where $\Delta n = (n_1 - n_2)/2$, $m = (m_1 + m_2)/2$, $\psi = g/\kappa$, and ϕ is the relative angle of the phase orientations of the error ellipses of the modes. It is clearly seen that the interaction stimulates a process which converts the varying intra-mode population difference into the first-order coherence whereas the varying intra-mode two-photon correlations are converted into the inter-mode two-photon correlations.

In the case of the nonlinear parametric interaction the varying populations of the modes are converted into the two-photon inter-mode correlations, whereas the varying intra-mode two-photon correlations are converted into inter-mode one-photon coherence

$$\langle a_1 a_2 \rangle = -\left(n + \frac{1}{2}\right) \sinh \psi \cosh \psi = \frac{1}{2} \frac{\partial}{\partial g} \left[\left(n + \frac{1}{2}\right) \cosh^2 \psi \right] = \frac{1}{2} \frac{\partial}{\partial g} (\langle a_1^\dagger a_1 \rangle + \langle a_2^\dagger a_2 \rangle) \quad (3)$$

$$\langle a_1^\dagger a_2 \rangle = -m \cos \phi \sinh \psi \cosh \psi = \frac{1}{2} \frac{\partial}{\partial g} (m \cos \phi \cosh^2 \psi) = \frac{1}{2} \frac{\partial}{\partial g} (\langle a_1 a_1 \rangle + \langle a_2 a_2 \rangle) \quad (4)$$

The above expressions show that the two interaction processes create inter-mode correlations under completely different conditions. From Eqs. (1) and (2) we see the linear type interaction requires some kind of asymmetry between the modes, e.g. unequal populations ($n_1 \neq n_2$) and different orientations of the error ellipses. Eqs. (3) and (4) show that the parametric type interaction requires symmetry between the modes.

Thus, in the realizations of this model one can control the output state of the modes which depending on the type of the interaction and the state of the modes can vary from coherent to entangled.

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Single-pair measurement of the Bell parameter and investigation of novel nonlocality bounds

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Since its birth, Quantum Mechanics has notoriously shown its counterintuitive traits, although maintaining its internal self-consistency. A clear example of this is represented by Bell inequalities [1], that in 1965 turned a philosophical debate into a physical experiment capable of extracting the true nature of correlations within physical systems, opening several research fields spanning from quantum mechanics foundations to quantum technologies [2]. Although loophole-free Bell inequality tests have been eventually realized [3-5], it was always deemed impossible to measure the entire Bell parameter on a single quantum system, a task forbidden by the Heisenberg uncertainty principle and the measurement-induced wave-function collapse. Defying this conviction, here we present the first realization of a weak-interaction-based method (see Fig. 1) for estimating the entire Bell parameter from each entangled pair while preserving the entanglement within the particles [6]. Since this method prevents the state from collapsing, one can measure multiple (incompatible) observables on the same quantum state, extracting all the correlations needed to evaluate the full Bell parameter from each pair (although with a large uncertainty, as it usually occurs with weak measurements). Besides providing new insights into some aspects of quantum foundations, like the concept of counterfactual definiteness [7], the fact that here the entanglement remains almost unaltered after its certification allows realizing further information protocols or quantum foundations experiments. Finally, we exploited this feature to test a novel nonlocality bound based on a recently-introduced principle dubbed Relativistic Independence [8], explicitly showing the intertwining between local and nonlocal correlations [9].

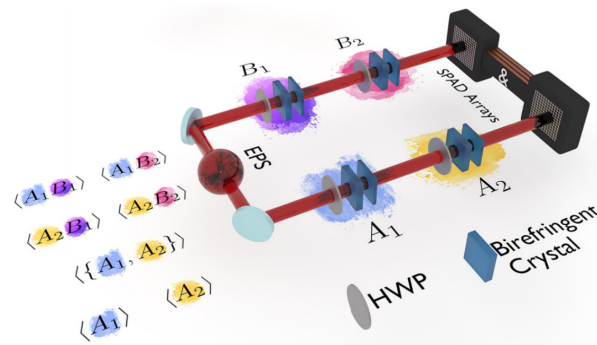


Fig. 1: The scheme of the experimental setup. Our entangled pair source (EPS) generates entangled photon pairs in the state $|\psi^-\rangle = (|H_A V_B\rangle - |V_A H_B\rangle)/\sqrt{2}$, sending one photon to Alice (A) and the other to Bob (B). Both A and B implement two Weak Measurements in a row, each carried by a pair of birefringent crystals preceded by a halfwave plate (HWP), setting the measurement bases. With this sequence, we are able to weakly couple the transversal spatial distribution and the polarization degrees of freedom of the photons. Then, both photons A and B are detected by a two-dimensional (2D) spatially resolving detector with internal time-tagging capability, with dedicated coincidence electronics (labelled as “&”). This scheme prevents the $|\psi^-\rangle$ state from collapsing, although at the cost of some small disturbance, allowing us to estimate all the measurement correlations required for measuring the Bell parameter and testing the Relativistic Independence principle [5].

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Genuine Continuous Quantumness

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Heisenberg's uncertainty principle reveals the existence of intrinsic noise in continuous variable systems. Usually, it is explored via quantum states with Gaussian squeezing. Insufficiency of Gaussian states for advanced quantum applications shifts attention into the non-Gaussian domain, which is quite a complex space. Whereas quantumness comes naturally to discrete variable systems, in continuous ones, its preparation and verification are challenging, especially in the presence of experimental imperfections. We present generalized nonlinear squeezing as a new powerful framework that distinguishes genuine quantumness, non-Gaussianity, in an intrinsic noise of continuous systems. The concept is based on cost functions that seek a target shape of the noise distribution and a threshold that distinguishes it from Gaussian states. Further, we experimentally prepare multi-photon-added coherent states and use generalized nonlinear squeezing to certify their non-Gaussianity via observing the effects of cubic and quintic order [1].

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Optical manipulation of ultra-cold Yb atoms for state preparation and measurements of atom-light interactions

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Optical manipulation of the energy level structure of ultra-cold atomic clouds can be used as an alternative to an external magnetic field. Sometimes this is necessary because the atomic states are magnetically insensitive, such as in the optical Stern-Gerlach protocol in the ground state of fermionic Yb isotopes. But it is also important when one faces time-sensitive applications, i.e., when the switch time of the coils used to create the magnetic field is too slow for the dynamics that one is interested to study. Here, we present recent experimental progress in the manipulation of ultra-cold ^{174}Yb atoms with optical frequencies. We exploit the $^3P_1 - ^3D_1$ transition to manipulate the energy level structure, and we demonstrate: i) the preparation of an ensemble of atoms in the excited state at the core of a larger cloud of atoms in the ground state [1]. These results lead to the measurement of light diffusion coefficient from inside the atomic sample, as opposed to the typical situation where the light propagates from outside the medium; ii) Using multiple frequencies we also gain independent control over the three degenerate energy levels of the 3P_1 state, and we are able to observe an all-optical Faraday rotation effect on the polarization of incident light on the sample [2]. Then, we will briefly discuss the implications of these experimental progress towards the realization of 3D Anderson localization of light in an atomic medium.

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Atom State Interferometer with Vector light beam

Tue – 20

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Perhaps one of the most salient features of light is the fact that it can interfere, particularly vector light correlated with polarization and spatial degrees of freedom shows fascinating behaviour in the context of interference. [1, 2]. On the other hand, an atom can be a valuable interface to shape light because by its very nature the atomic dipole interactions are sensitive to polarization via selection rules [3]. In this work, our goal is to investigate the role of structured light for atom state interferometers, where it facilitates local interference dictated by the orientation of an external magnetic field, optical and atomic polarization.

Here, we realize an atom state interferometer in ^{87}Rb driven by a vector light beam which excites two optical transitions from $F = 1$ to $F' = 0$ hyperfine state in a Λ (fig1(a)) configuration and a transverse magnetic field couples between the ground levels creating a closed loop configuration to make a phase sensitive system. We consider a very generic form of light field embedded in left and right hand circular polarization to study internal dynamics of Rb^{87} atom delving into a fully analytical description. We investigate the inner atomic process observing transition probabilities between our derived partially dressed states according to some order of perturbation theory. The results show that the transition rates between the partially dressed states depends on the phase and polarization profile of the light, as specified by the coordinates on a Poincare sphere[4], and the direction of the external magnetic field.

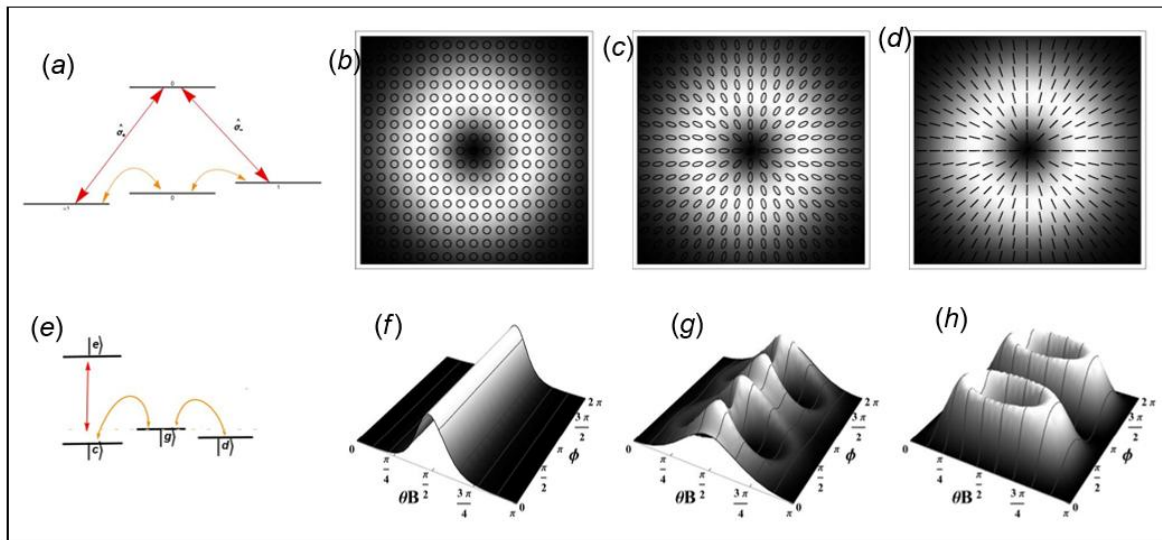


Fig. 1: (a): Atomic level scheme (Ground states ± 1 couples optically to the excited states and also the ground states $\pm 1, 0$ states are coupled by transverse component of an external magnetic field), (e): partially dressed state basis form a ladder like system, where the excited state $|e\rangle$ coupled optically and $|c\rangle, |g\rangle$ and $|d\rangle$ are magnetically coupled. (f), (g) and (h) show transition rates between $|d\rangle$ to $|e\rangle$ with varying magnetic field angle (θ_B) corresponding to different beam profiles ((b) the probe is homogeneously right circularly polarized (RCP), (c) Arbitrary polarized and (d) radially beam. It is also to be noted that for homogeneously RCP beam as the close loop configuration (fig1: a) disappears results in the vanishing of spatial phase dependency in absorption.

Our fully analytical model allows to associate parameters of the structured light with specific atomic transition rates, and hence absorption profiles. Our study enhances the understanding of vector light-atom interaction, and may pave the way to designing devices for quantum magnetometry and metrology.

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Collective light shifts of many cavity modes probed by an optical frequency comb

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Optical resonators have been a mainstay of atomic physics for the last four decades. The considerable enhancement of light-atom interaction, provided by coupling to a high quality optical cavity, has led to unprecedented levels of quantum control, down to single atoms and photonic quanta. When the cavity mode is tuned close to an atomic resonance, the coupling leads to photon exchange oscillations between the atoms and the cavity mode due to vacuum Rabi splitting [1]. For an ensemble of cold atoms, the dispersive regime of this interaction, occurring when resonator frequency is detuned sufficiently far from the optical transitions that photon absorption is negligible, has also proven crucial for inducing spectacular collective effects such as cavity cooling [2], spin squeezing [3] and self-organization [4].

So far, this dispersive interaction regime has only been studied using a single or few longitudinal cavity modes at a time. We experimentally study the dispersive interaction between a cold atom cloud and many longitudinal modes of a Fabry-Perot resonator, by detecting collective light shifts in the transmission spectrum of an optical frequency comb probe. Using a high quality resonator and around 10^5 intracavity atoms, we detect appreciable shifts of more than 50 cavity modes simultaneously. These results constitute a first demonstration of dispersive interaction of matter with many longitudinal modes of a linear resonator, and pave the way towards the optomechanical cold atom interaction regime with femtosecond pulsed light.

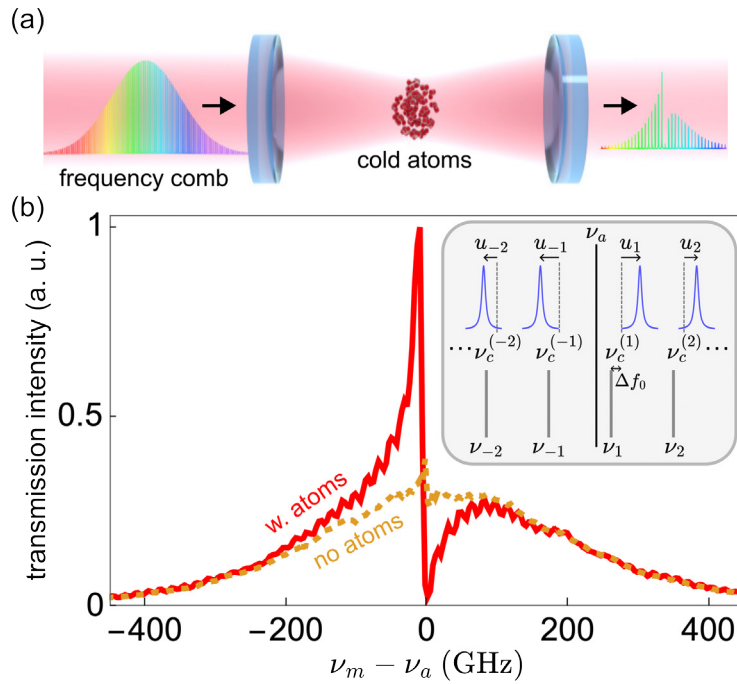


Fig. 1: Measuring the collective light shift of many longitudinal cavity modes induced by dispersive interaction with cold atoms. (a) A cold atom cloud is placed inside a Fabry-Perot resonator driven by an optical frequency comb. (b) The cavity transmission is detected at a spectrometer, showing a marked difference in spectra when the atoms are present or not. The cavity modes are shifted by u_j due to light-matter interaction, and the strength of the shift is inversely proportional to the detuning of the cavity mode $\nu_c^{(j)}$ from the two-level optical transition of the atoms ν_a . We detect appreciable shifts of more than 50 cavity modes simultaneously when a cold atom cloud is loaded into the resonator.

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Towards Light Scattering Experiments in Dense Dipolar Gases

Tue – 22

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In ensembles of ultracold atoms where interatomic spacing is smaller than the wavelength of scattered light, direct matter-matter coupling through electric & magnetic interactions significantly influences system dynamics, leading to a regime where atoms cannot be treated as independent emitters. In this context, we aim to study the role of magnetic dipole-dipole interactions (DDI) in the cooperative behavior exhibited by dense atomic ensembles of dysprosium, which has the highest ground-state magnetic moment (10 Bohr magnetons) of all elements in the periodic table. Light-scattering experiments are a standard tool to probe these effects experimentally.

This poster reports on the progress made in generating dense dysprosium clouds, including optical transport of atoms into a home-built science cell with high optical access. The creation and imaging of the samples is achieved using high NA custom objectives, designed and assembled in-house. We present recent measurements outlining the impact of trapping light polarization on atomic lifetime and temperature. Further, an outlook is given on future measurements exploring collective and cooperative effects in our sample.

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Discrete diffraction and discrete solitons in optically induced lattices in atomic vapor

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We present an experimental study of the propagation of light through 1D and 2D optically induced lattices by a far-detuned Λ system in Doppler-broadened ^{87}Rb atomic vapor. Discrete diffraction patterns are observed when a probe beam, initially focused to a single lattice site, propagates through the optically induced lattice. We investigate the influence of various experimental parameters, such as probe beam size, probe and coupling laser detunings and intensities, and the concentration of atoms on the observed diffraction patterns and the patterns' contrasts. At higher probe powers we also observe the formation of discrete solitons.

These periodic structures in atomic systems are analogous to weakly coupled waveguides, yet they have tunable optical properties. As such, they provide a powerful experimental platform that can enable the exploration of complex quantum and optical physics phenomena, such as non-Hermitian physics, Aubry–André localization, PT-symmetric potentials [1], and photonic Floquet topological insulators [2].

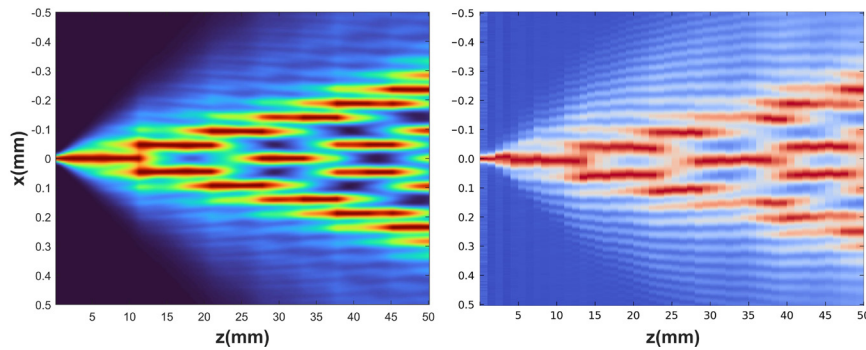


Fig. 1: Simulated (left) and measured (right) propagation of light through an optically induced one-dimensional lattice in rubidium vapor.

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Emergent Lee-Huang-Yang physics from a Wigner representation of the Bose field

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We present a theoretical framework for incorporating beyond-mean-field Lee-Huang-Yang (LHY) physics [1] into the truncated Wigner representation of an ultracold Bose gas. This is achieved by generating a Bogoliubov ground-state representation [2] with an appropriately tailored bare interaction strength g_0 and condensate density n_0 , ensuring identical initial energy and density conditions for both mean-field and Wigner field dynamics. This approach allows for the study of quantum correlations, coherence decay, and condensate fraction beyond the scope of the extended Gross-Pitaevskii equation (EGPE). Numerical simulations in one-dimensional Bose-Einstein condensates demonstrate that observables significantly deviate from both the plain Gross-Pitaevskii equation (GPE) and EGPE, with the latter failing to provide clear improvements over the former. In particular, interference effects predicted by these mean-field approaches often vanish entirely. In a system subjected to a periodic trapping potential, the truncated Wigner method qualitatively reproduces the expected beyond-mean-field behavior while revealing that certain interference patterns from the EGPE are unphysical. This establishes the truncated Wigner approximation as a powerful alternative for capturing emergent LHY physics in regimes where quantum correlations are non-negligible.

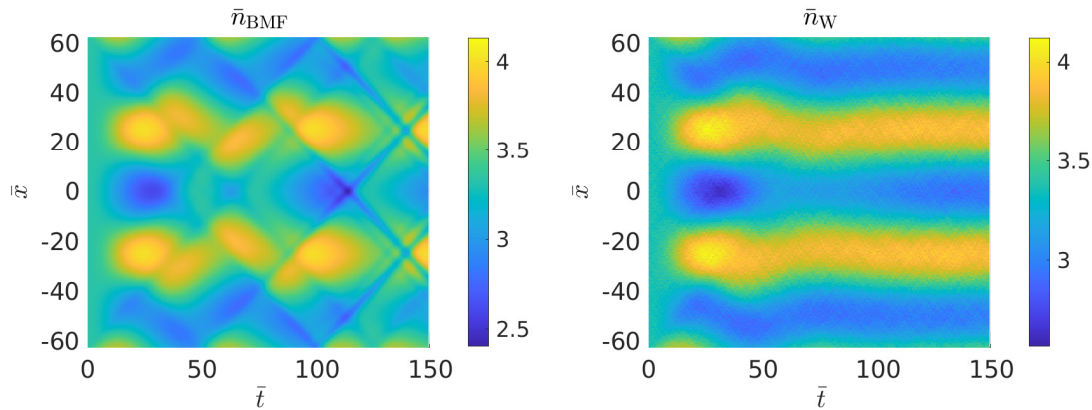


Fig. 1: Density evolution of an initially homogeneous Bose gas in a periodic trapping potential, $\bar{V}(\bar{x}) = \frac{1}{10} \cos(\frac{\bar{x}}{8})$, where $\bar{x} = \frac{x}{x_0}$ and $x_0 = \frac{\hbar}{\sqrt{mg n}}$. **Left:** Extended Gross-Pitaevskii Equation (EGPE) prediction, governed by $i \frac{\partial \bar{\psi}}{\partial \bar{t}} = \left[-\frac{\bar{\nabla}^2}{2} + \bar{V}(\bar{x}) + \bar{g}|\bar{\psi}|^2 - \frac{\bar{g}^{3/2}}{\pi}|\bar{\psi}| \right] \bar{\psi}$, where $\bar{g} = \frac{mgx_0}{\hbar^2} = 0.3$ and $\bar{g}\bar{n}(\bar{t}=0) = 1$. A sharp interference pattern emerges at $\bar{t} > 50$. **Right:** Gross-Pitaevskii Equation (GPE) prediction from the Bogoliubov ground state in the Wigner representation, $\bar{\psi}_W$, evolving according to $i \frac{\partial \bar{\psi}_W}{\partial \bar{t}} = \left[-\frac{\bar{\nabla}^2}{2} + \bar{V}(\bar{x}) + \bar{g}_0|\bar{\psi}_W|^2 \right] \bar{\psi}_W$, where $\bar{g}_0 = 0.2718$. The interference pattern vanishes, indicating that the structures observed in the EGPE solution are unphysical [3].

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Tue – 25

Numerical investigation of simultaneous spin-squeezing of fermionic mercury isotopes in natural abundance vapor cells

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We investigate the use of optically-addressable nuclear spins in the fermionic isotopes of Mercury (^{199}Hg and ^{201}Hg) for generating macroscopically entangled spin squeezed states [1,2] in hot atomic vapors. We present a quantum interface for calculating the Wineland spin squeezing criterion [3] under the influence of different atomic loss and spin decoherence sources as well as inhomogeneous atom-light coupling within the Gaussian approximation [4] of atomic spin- f states. The novel aspects about our work are 1) generalizing the Gaussian-approximation-based quantum interfaces [4,5] to spin- f systems where $f > 1$, and 2) investigating the simultaneous spin squeezing of two optically-addressable nuclear spins (^{199}Hg and ^{201}Hg) in an atomic ensemble of natural-abundance mercury.

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Gauge theories from generalized blockade in decorated Rydberg arrays

Tue – 26

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Nowadays, controllable quantum systems offer the unprecedented opportunity to study phase diagrams and dynamics of strongly coupled gauge theories by engineering their lattice Hamiltonian [1]. Rydberg atoms in reconfigurable optical tweezers proved to be an excellent platform to implement spin-like Hamiltonians in ultracold atom experiments [2]. Due to their controllability and adaptability, they are highly suited to simulate a wide range of physical models while their scalability enables the investigation of dynamics in large-scale setups. In my presentation, I will consider the well-known Rokhsar-Kivelson Hamiltonian [3], a 2D $U(1)$ lattice gauge theory describing quantum dimer and spin-ice dynamics, in different geometries. I will show a realistic proposal for realizing the model and probing its rich phase diagram in a Rydberg atom setup. By applying a dual mapping, it is possible to describe the Hamiltonian's plaquette interactions as an Ising spin model with projectors displaying both blockade and anti-blockade behavior [4]. To simulate the combination of these conditions, anisotropic interactions between spins are needed, making a realization in conventional Rydberg setups challenging. I will explain how to engineer tunable anisotropic attractive as well as repulsive interactions with so-called superatoms by organizing two or more individual atoms in small clusters sharing one Rydberg excitation [4]. Controlling the couplings between these superatoms translates into the desired blockade and anti-blockade conditions and enables a realistic implementation of such models. I will present practical protocols to adiabatically prepare the resonating valence bond solid phase of the Rokhsar-Kivelson Hamiltonian, and discuss their suitability for Rydberg arrays of strontium atoms. Finally, I will show that we can investigate variants of the Rokhsar-Kivelson model corresponding to other generalized blockade conditions, by simply tuning the geometry both adiabatically as well as diabatically using quantum quenches.

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Persistent oscillation of a Cooper-pair condensate of topological defects in a nonintegrable quantum Ising chain

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We identify persistent oscillations in a nonintegrable quantum Ising chain. In the integrable chain with only nearest-neighbor interactions, the nature, origin, and decay of post-transition oscillations are tied to the Kibble-Zurek mechanism [1]. The Hamiltonian of the integrable Ising chain is given by

$$H = - \sum_{n=1}^L (g\sigma_n^x + \sigma_n^z\sigma_{n+1}^z + J_2\sigma_n^z\sigma_{n+2}^z), \quad (1)$$

where $\sigma_n^{x,y,z}$ are Pauli operators at site n , g is the transverse field, and $J_2 = 0$ is the next to nearest-neighbor ferromagnetic coupling strength. Remarkably, when next-nearest neighbor coupling is introduced (*i.e.*, $J_2 = 1$), the resulting nonintegrable “zigzag” chain (which remains in the quantum Ising universality class) supports persistent oscillations. In this “zigzag” quantum Ising chain (which can be implemented with only nearest-neighbor couplings on a zigzag ladder; see Fig. 1), topological defects (dressed kinks—fermionic Bogoliubov quasiparticles that appear below the critical transverse magnetic field) give rise to tightly bound Cooper pairs as the lowest branch of excitations. The oscillation frequency of the Cooper-pair condensate depends on the binding energy gap between paired and unpaired defects, allowing it to be excited by resonant driving. While one might expect the integrability-breaking “zigzag” coupling J_2 to induce relaxation, the oscillations we identify persist indefinitely—once excited, they show no signs of decay. In our simulations, their longevity appears limited only by numerical accuracy. This oscillation of the Cooper-pair condensate of kinks is a manifestation of quantum coherence and should be experimentally accessible.

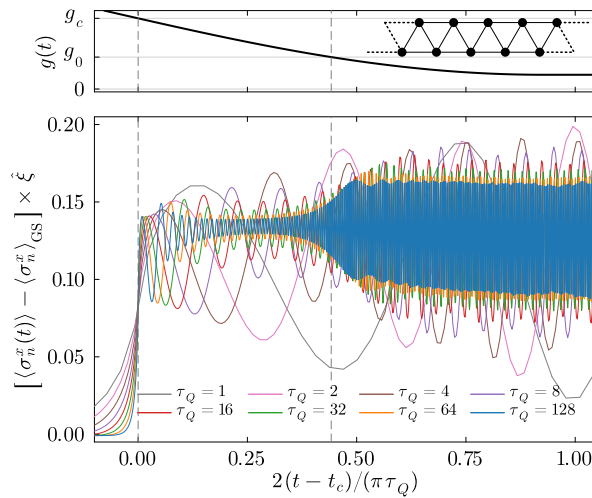


Fig. 1: Persistent coherent oscillation in the zigzag Ising chain compared and contrasted with the decaying post-KZM oscillations after a quench into the ferromagnetic phase. Top: The KZ ramp crossing the critical point at $g_c = 2.47725$ to end in the ferromagnetic phase at nonzero $g = 0.5$. The inset shows the zigzag ladder. Bottom: Rescaled transverse magnetization $\langle\sigma_n^x(t)\rangle - \langle\sigma_n^x\rangle_{\text{GS}}$ during the ramp as a function of time, where $\langle\sigma_n^x\rangle_{\text{GS}}$ is its value in the adiabatic ground state and $\xî = \sqrt{\tau_Q}$ is the KZ length. Its oscillation amplitude suddenly increases in the middle of the ferromagnetic phase near $g_0 = 1.12$.

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Challenges in Quantum Spectral Shearing Interferometry for Measurement of Narrow-Bandwidth Pulses

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Narrow-bandwidth single-photon pulses with durations ranging from a few to a few dozens of picoseconds are an important tool in quantum communication and quantum sensing. Some of the benefits of such pulses include low dispersion dependence and the ability to effectively match the absorption lines of broadband quantum memories. Quantum networks can also use picosecond single-photon pulses emitted by quantum dots, which serve as a convenient on-demand single-photon source. However, the narrow spectral bandwidth of such pulses makes their characterization challenging. In this work, we examine whether Spectral Phase Interferometry for Direct E-field Reconstruction (SPIDER) can be used for this purpose. We investigate the limitations and advantages related to this method by working with the telecom wavelength classical light with the ultimate goal of transferring our research to the single-photon counting regime. We propose using the Shaper-Assisted Collinear (SAC) SPIDER to increase the accuracy of the setup.

SPIDER is a well-established technique for spectral phase retrieval, based on interfering two copies of a pulse with a relative temporal delay and spectral shift (shear). The captured interferogram provides information about the SPIDER phase – the spectral phase derivative – which enables characterization of the electric field of the pulse. The accurate characterization of broadband single-photon pulses using electro-optic SPIDER was demonstrated in [1]. The setup used in this approach, which is also the architecture of our choice, was fully fiber-based, minimizing phase variations due to environmental factors and making it ideal for long acquisition photon counting.

Before moving into the quantum regime, we successfully measured spectral phases of classical pulses at 1550 nm wavelength with a spectral width of 1.5 nm and identified several challenges in further reducing this value. Polarization crosstalk introduces low-intensity pre-pulses, which cause shear-independent rapid oscillations in the SPIDER phase. Measuring narrower pulses requires reducing the shear, which in turn lowers the amplitude of the measured SPIDER phase. Since the noise level remains constant, the signal-to-noise ratio decreases. This source of noise has been modeled and identified as the key limitation of SPIDER in the narrow-bandwidth regime. However, challenges also arise in the time domain, where spectrally narrow pulses have long time durations. This makes filtering out pre-pulses impossible and complicates the application of a homogeneous spectral shift.

Additionally, accurately measuring the spectral shift – close to resolution of the spectrometer – becomes problematic. To overcome this challenge, we suggest using the Shaper-Assisted Collinear (SAC) SPIDER method [2]. In this setup, the temporal delay is introduced via a sinusoidal intensity filter applied by an optical pulse shaper. We propose to kill two birds with one stone and use the pulse shaper to introduce an additional known parabolic spectral phase. By comparing the captured SPIDER phase with the known input, the shear value can be determined with high accuracy, which is not achievable through direct measurement.

A key limitation of SAC SPIDER is the maximum delay before distortion occurs (40 ps in our case), although state-of-the-art technology could, in principle, extend this over 5 times. This would enable the characterization of very spectrally narrow single-photon pulses, which are used for encoding information in standard quantum memories [3]. Research in this area is ongoing, but we anticipate that SAC SPIDER may also offer additional benefits, including: 1. Reduced pre-pulse amplitude, as polarization degrees of freedom are no longer used. 2. Simplified implementation. 3. Improved phase stability due to the collinearity of the system.

We believe that with further refinements, electro-optic SAC SPIDER could become a powerful tool for characterizing narrow-bandwidth single-photon pulses.

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Emission from driven atoms collectively strongly coupled to an optical cavity

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The study of driven atoms coupled to cavities has focused on either the single-atom-cavity strong coupling regime or the bad-cavity limit [1,2]. However, between these well-explored domains lies an exciting and richly complex intermediate regime, where a large ensemble of atoms collectively interacts with a cavity, unlocking a host of novel physical phenomena and applications.

Our group has demonstrated minimal destruction detection techniques for atoms, ions and molecules by leveraging these collective interaction effects on vacuum Rabi splitting and cavity enhanced electromagnetically induced transparency [3-7]. Remarkably, when such a collectively interacting atoms-cavity system is driven, one can observe self-sustained emission from the cavity despite the lack of any direct input to the cavity mode [8-10]. Exploring the statistical properties and mechanisms of this cavity emission holds potential for creating bright sources of identical-photon pairs, enabling lossless state detection, ultra-narrow linewidth transitions for atomic clocks and developing cavity-based quantum technologies [11-13].

Here, we present a detailed study of cavity emission from a large ensemble of driven atoms in collective strong coupling with an optical cavity. The cavity emits light over a broad range of atom-cavity and drive laser detunings. Second-order correlation measurements ($g^{(2)}(\tau)$) reveal unexpected features in the cavity emission, including (a) damped oscillations at two distinct frequencies and (b) significantly different $g^{(2)}$ values for different polarization components. Measurements indicate the presence of two separate, polarization-decoupled mechanisms with distinct photon statistics, which transfer energy from the drive field to the cavity field. The statistical properties and underlying mechanisms of cavity emission explored in this work may help extend non-destructive detection techniques into the collective strong coupling regime.

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Polarization-entangled Spectral Vector Photons

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Light without a uniform polarization structure is often termed as an optical vector field. Popular examples are structured light fields where the polarization varies across transverse spatial degree of freedom, the so-called spatial vector beams, where radially or azimuthally polarized beams are prime examples. In addition a lot of attention has also been put towards structuring vectorial light fields over its temporal or spectral extent, resulting in a polarization that varies over the pulse duration or frequency spectrum. The complex combination of all degrees of freedom is called high-dimensionally structured light or simply structured light [1,2]. In the quantum domain, structuring the shape of single photons has been studied, e.g., in applications such as high-dimensional quantum communications, simulations, imaging, or quantum metrology, to name a few.

In this work, we explore single photons with complex polarization patterns across the frequency spectrum, which we call spectral vector photons (SVPs) in analogy to their classical counterparts [3]. We further show that these patterns can be entangled with the polarization of their partner photon, allowing a remote preparation of their complex spectral shape.

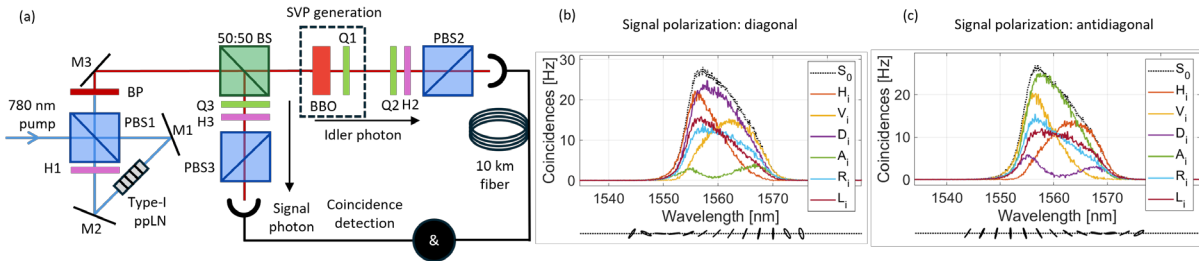


Fig. 1: Experimental observation of SVP. (a) Experimental setup. M: mirror, H: half waveplate, PBS: polarizing beam splitter, BP: 1560 nm bandpass filter, Q: quarter waveplate, BBO: Beta Barium Borate crystal. Spectral profile of idler SVP at different polarization projections corresponding to (b) diagonally and (c) anti-diagonally polarized signal photons. The retrieved spectral variation of polarization is illustrated by the polarization ellipses.

In the experiment, we generate polarization entangled photon pairs from a Type-I periodically poled Lithium Niobate (ppLN) crystal placed in a Sagnac interferometer for spontaneous parametric down conversion (see Fig. 1 (a)). The crystal is pumped with a 780 nm pulsed laser (~ 200 fs pulse-width, 80 MHz repetition rate) and produces polarization-entangled photon pairs at 1560 nm with the polarization state being $1/\sqrt{2}(|H_s\rangle|H_i\rangle + |V_s\rangle|V_i\rangle)$ where H/V corresponds to horizontal/vertical polarization of the two down converted photons – signal (s) and idler (i). The idler photon is passed through a birefringent Beta Barium Borate (BBO) crystal followed by a quarter waveplate (Q1), which introduces a delay τ between right (R_i) and left (L_i) circularly polarized parts of the photon. This temporal configuration leads to an SVP depending on the initial polarization state of the idler photon and, thus, on the polarization of its signal partner photon through the virtue of entanglement. For example, for a signal photon found in diagonal polarization D_s , the idler photon will have a spectrally varying polarization state $1/\sqrt{2}(|R_i\rangle + e^{i\pi c\tau/\lambda}|L_i\rangle)$. Different polarization states of the signal lead to different initial polarizations of the idler and therefore results in different polarization structures of the SVP. The spectral profile of this photon is experimentally captured using the dispersive Fourier transformation by a 10 km long fiber. We retrieve its polarization structure using polarization tomography implemented through waveplates (Q2, H2) and a polarizing beam splitter (PBS2). The experimentally obtained spectra for different polarization projections and the resulting spectral evolution of the polarization state are depicted in Fig. 1 (b) with the signal projected in diagonal polarization. Projecting the signal photon on anti-diagonal polarization leads to a reversed polarization evolution in the spectrum of the corresponding idler SVP (see Fig. 1 (c)). To prove the entanglement between signal polarization and the polarization structure of SVP, we further confirm that each frequency of the SVP individually violates a Bell inequality.

Our work paves the way for multi-dimensional structured quantum photonics and will find potential application in quantum spectroscopy or other sensing tasks.

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Quantum Sensing of Exotic Spin Interactions with a Spinor BEC Comagnetometer

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We present a quantum-noise-limited comagnetometer platform based on a single-domain spinor Bose-Einstein condensate (sBEC), optimized to search for spin-dependent forces such as spin-gravity and axion-like particle (ALP) interactions. This platform builds upon a magnetometry demonstration with record energy resolution per bandwidth $E_R = 0.075 (16) \hbar$, corresponding to a single-shot sensitivity of 72 (8) fT in a $1091 (30) \mu\text{m}^3$ volume over 3.5 s (Fig. 1a) [1]. This performance results from the fully-coherent, ultracold nature of the sBEC, which avoids the density vs. coherence trade-off common to conventional spin-precession sensors [1, 2]. We model the quantum noise dynamics using the truncated Wigner approximation, incorporating interaction-induced spin shearing, atomic loss, and quadratic Zeeman shifts.

Building on the magnetometer's demonstrated performance, we estimate the projected sensitivity of the comagnetometer using its measured noise characteristics, as shown in Fig. 1b. The comagnetometer configuration enables differential measurements that reject magnetic field noise while maintaining sensitivity to exotic spin couplings. These projections are based on a spin-dependent interaction generated by ALP exchange, which gives rise to a monopole-dipole potential between unpolarized and polarized fermions [3]. Under this assumption, the comagnetometer would improve existing laboratory limits on ALP-mediated monopole-dipole couplings to protons by up to six orders of magnitude [4]. This platform enables precision searches for fundamental spin interactions at short ranges, offering a new path to probe physics beyond the Standard Model.

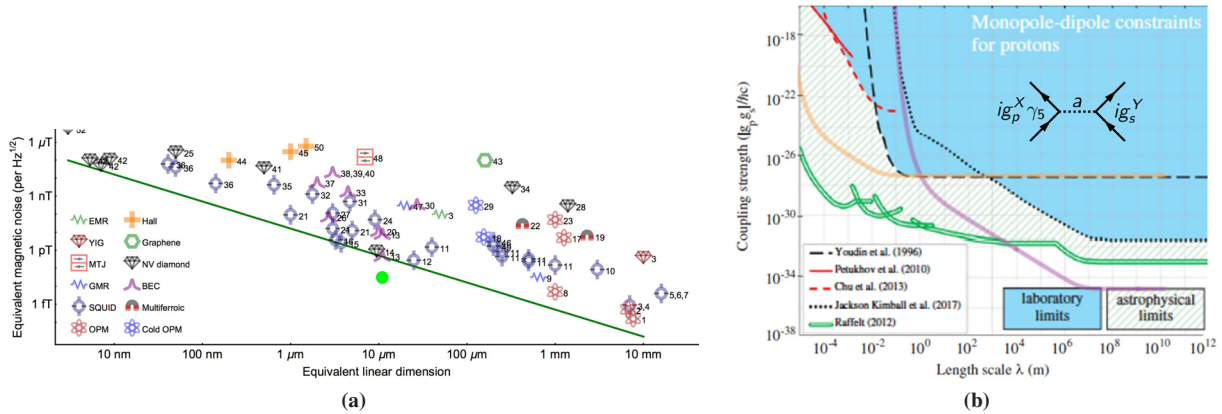


Fig. 1: Sensitivity and science reach of the sBEC comagnetometer platform. (a) Demonstrated energy resolution of the sBEC magnetometer (green), surpassing all other reported sensors in volume-adjusted noise [1]. (b) Projected reach for ALP-mediated spin-dependent forces coupling to protons, adapted from [4], with added sBEC comagnetometer sensitivity curves based on its measured noise performance. The orange curve assumes a tungsten source at $100 \mu\text{m}$; the violet curve models the Earth as the source.

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Coherence, entanglement, and superradiance

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In 1954 Robert Dicke proposed a novel description of spontaneous light emission in a system of particles coupled to an electromagnetic field [1]. Prior to this, the concept of light emission had been described as radiation of photons emitted by *independent* particles. This approach is indeed justified if the typical distance between emitters is larger than the wavelength of emitted light waves. However, if the close proximity of emitters cannot be neglected, as Dicke argued, spontaneous light emission is better described as a *collective* phenomenon of particles, which are correlated with one another since they are influenced by each other's radiation field.

Since the emitters are initially prepared in their excited state, they would eventually decay into ground state at a certain rate as the system evolves. If the emitters evolve independently, then the decay rate is proportional to the number of emitters, N . In contrast, Dicke's picture deduces that the collective behavior of the emitters leads to their decay to scale at a rate of N^2 , resulting in 'superradiance', a term introduced to characterise the sudden burst of emitted light.

Building upon our previous work [2] we investigate the correlations of spin- $\frac{1}{2}$ emitters coupled to a single bosonic mode whose time-evolution is governed by Tavis-Cummings hamiltonian [3]

$$H = h_{\text{emitters}} + h_{\text{interaction}} + h_{\text{photons}} = \sum_{i=1}^N \frac{1}{2} \omega_q \sigma_i^z + g \sum_{i=1}^N (\sigma_i^+ \alpha + \sigma_i^- \alpha^\dagger) + \omega_c \alpha^\dagger \alpha,$$

where ω_q is the resonance frequency of a two-level emitter, g is the coupling strength, while ω_c is the angular frequency of the emitted photon. We treat this as an open quantum system subject to decay, photon loss and pure dephasing at rates γ , κ and γ_ϕ , respectively. We solve the Lindblad quantum master equation to evolve the system in time, and measure correlation through an entanglement witness, W , relative coherence, C_{rel} and the von Neumann entropy, S . We investigate whether Dicke's picture on superradiance is valid, i.e., does the correlation of emitters enhance spontaneous light emission?

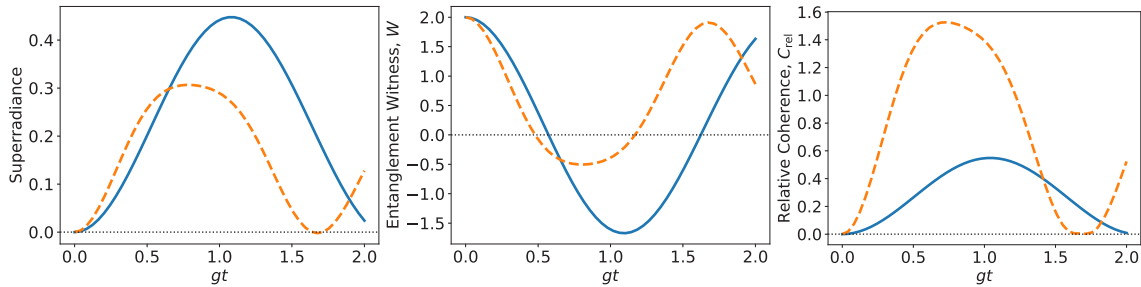


Fig. 1: (left) The superradiance $\langle \sigma_i^+ \sigma_j^- \rangle$ is shown as a function of time. (middle) The time evolution of entanglement witness, W is depicted. (right) The relative coherence, C_{rel} is plotted for the same duration as in the left and middle graphs. Blue solid lines correspond to $N = 2$, while the dashed orange lines represent $N = 4$. The other common parameters are: $g = 1$, $\frac{\gamma}{g} = 0.0$, $\frac{\kappa}{g} = 0.1$, and $\frac{\gamma_\phi}{g} = 0.0225$.

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Spin noise spectroscopy of an alignment-based atomic magnetometer

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Optically pumped magnetometers (OPMs) are revolutionizing the task of magnetic-field sensing due to their extremely high sensitivity combined with technological improvements in miniaturization which have led to compact and portable devices. OPMs can be based on spin-oriented or spin-aligned atomic ensembles which are spin polarized through optical pumping with circular or linear polarized light, respectively. Characterization of OPMs and the dynamical properties of their noise is important for applications in real-time sensing tasks. In our work, we experimentally perform spin noise spectroscopy of an alignment-based magnetometer. Moreover, we propose a stochastic model that predicts the noise power spectra exhibited by the device when, apart from the strong magnetic field responsible for the Larmor precession of the spin, white noise is applied in the perpendicular direction aligned with the pumping-probing beam. By varying the strength of the noise applied as well as the linear-polarization angle of incoming light, we verify the model to accurately predict the heights of the Larmor-induced spectral peaks and their corresponding linewidths. Our work paves the way for alignment-based magnetometers to become operational in real-time sensing tasks.

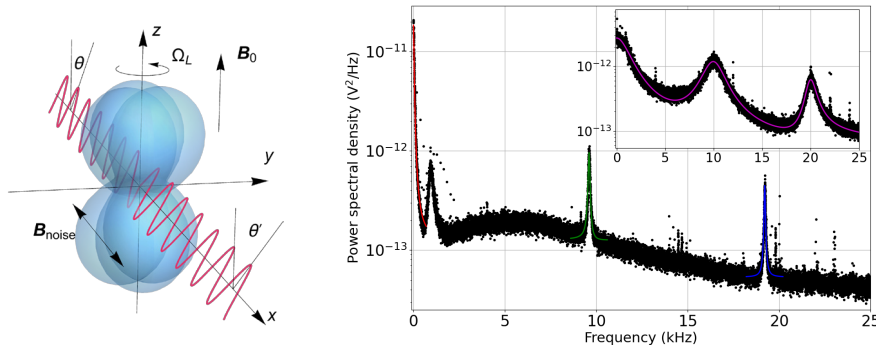


Fig. 1: The light propagates through the atomic ensemble in the presence of a strong, static magnetic field B_0 . A stochastic field B_{noise} is applied along the direction of light propagation, and induces noise that disturbs the atomic state from equilibrium. The light polarisation angle θ' is measured. We predict properties of the noise-spectrum of the signal.

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Impact of Temporal Fluctuations on Atom Interferometry

Tue – 34

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Quantum sensors based on atom interferometers achieve unprecedented sensitivity in inertial sensing, enabling high-precision tests of gravitational interactions and quantum mechanics. Differential configurations, for instance, probe the Einstein equivalence principle via dual-species acceleration comparisons [1], detect gravitational wave signatures, and constrain couplings to physics beyond the Standard Model [2]. While single-photon transitions intrinsically suppress laser phase noise [3], residual systematic uncertainties persist. Key challenges include time-varying gravitational gradients and low-frequency temporal noise in ambient gravitational fields, which limit long-term stability in terrestrial and space-based applications.

Including Standard-Model extensions like light, scalar fields such as dilaton fields into the description of the interferometer and the internal dynamics of the atom, cf. Fig. 1, we identify the key signature of possible dark-matter candidates [4], with direct applicability to gravitational-wave detection. Leveraging these findings, we investigate temporal noise contributions from diverse sources in atom interferometry. To this end, we bring all phase contributions on an equal footing, enabling direct comparisons with laser phase noise. By integrating local noise profiles into the analysis, we enhance phase analysis and improve overall sensitivity. Furthermore, we review current differential configurations [5] and systematically examine temporal noise across multiple origins, highlighting pathways for mitigating its impact on precision measurements.

This work advances the understanding of temporal noise in atom-based quantum sensors, enabling improved sensitivity and precision across diverse applications. By addressing temporal noise, we enhance the potential for gravitational-wave detection, equivalence-principle tests, and dark-matter exploration.

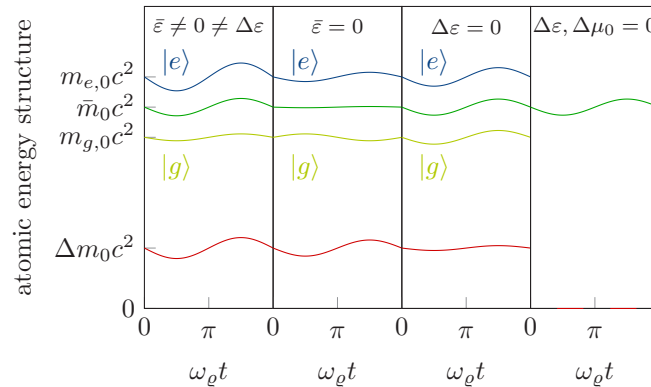


Fig. 1: The atomic energy levels oscillate due to the dilaton field ϱ with frequency ω_ϱ , affecting the ground state (light green), excited state (blue), mean atomic mass (green), and energy difference between both states (red). These oscillations depend on the mean coupling $\bar{\epsilon}$, differential coupling $\Delta\epsilon$ to the dilaton, and mass defect $\Delta\mu_0 = \Delta m_0/\bar{m}_0$, with implications for single-photon and Bragg-type schemes ($\Delta\mu_0 = 0$). The figure illustrates four cases: general couplings ($\bar{\epsilon} \neq 0 \neq \Delta\epsilon$), opposite couplings ($\bar{\epsilon} = 0$), identical couplings ($\Delta\epsilon = 0$), and the Bragg case [4].

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Quantum Sensing with Tanneled Clocks

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Ultracold gases represent a unique and versatile platform for a wide range of quantum sensing applications. Atom interferometers utilize large spatial separation of a superposition of cold atomic clouds to facilitate precise measurements of accelerations and inertial forces. At the same time, the inherent atomic structure serves as a fundamental element for precise timekeeping, utilizing atomic transitions for precise time measurements. By combining both external and internal degrees of freedom, novel applications and possibilities emerge.

The advent of ultracold clouds cooled below the Doppler limit enables coherent and precise manipulation of external degrees of freedom. These systems play a crucial role for the investigation of tunneling physics, relying on the manipulation and observation of the atomic motion. Furthermore, combining external and internal degrees of freedom provides insights into tunneling times and associated phenomena.

In classical mechanics, a particle's motion can be described by a well-defined worldline. In Quantum mechanics, however, such a description is not possible due to the inherent delocalization of quantum particles and associated phenomena like tunneling. But still, there exist strategies to assign a time to tunneled particles: Focusing on the arrival of the particle after tunneling leads to the arrival time [1] associated with a classical trajectory, while investigating its duration within the classically forbidden region provides the dwell time [2, 3]. In contrast to these definitions, we follow strictly an operational approach: Time is what you read off a clock.

In this contribution, we theoretically investigate the phase difference of tunneled quantum clocks [4] in various differential measurements. We identify relativistic contributions accumulated by a tunneled quantum clock due to time dilation and mass defect. In particular, we relate these contributions to a tunneling time and highlight the relations to conventional approaches.

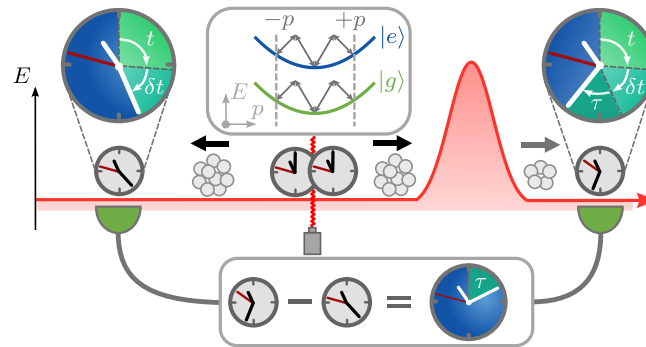


Fig. 1: To start the sequence, we create an equal superposition of two Ramsey clocks with opposite momenta $\pm p$, where one clock tunnels and the other serves as a reference. By performing a differential measurement, common phase contributions are canceled and from the remaining phase the tunneling time can be deduced. Figure taken from Reference [1].

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Robust Generation of N-Partite N-Level Singlet States by Identical Particle Interferometry

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We propose an interferometric scheme for the robust generation of totally antisymmetric N-partite N-level singlet states using identical bosons. These states serve as valuable resources for quantum communication and metrology applications, offering strong resilience against noise. Our approach employs a sequence of Fourier multi-ports combined with coincidence measurements to probabilistically filter the desired output state. The successful preparation of the generalized singlet is determined by the anti-bunching behavior of bosonic particles at each stage of the interferometer.

Our method is robust against local lossless noise and operates effectively even when the input state is a maximally mixed state. Unlike previous techniques that require quantum non-demolition (QND) measurements or feedback mechanisms, our protocol enables exact singlet state generation through postselected interference effects in multi-port beam splitters. Additionally, we present an implementation for the case of $N = 3$ that does not rely on QND measurements, simplifying experimental realizations. Our findings extend previous results on two-particle singlet generation to multipartite settings, highlighting the power of identical particle interference as a tool for entanglement engineering.

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Electro-Optic Frequency Shift of Single Photons from a Quantum Dot

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There is increasing interest in multiplexing different semiconductor quantum dots (QDs) to create indistinguishable multi-photon states for advanced quantum applications, such as boson sampling, quantum communication, and quantum networks. However, imperfections in the fabrication processes cause variations in QDs' emission wavelengths. Traditional in-situ wavelength tuning methods, based on, e.g., mechanical strain or temperature adjustment, while effective, are difficult to scale and often require sample processing. We demonstrate active frequency shifting of photons after they have been emitted from the QD using an electro-optic serrodyne frequency shift [1, 2].

The experiment utilizes a commercially available QD chip from Sparrow Quantum, which features InAs QDs embedded in a photonic crystal waveguide [3]. The QDs emit photons within the wavelength range of 920–940 nm and are resonantly excited using a pulsed ps Ti:Sapphire laser. The emitted photons are then passed through an electro-optic phase modulator (EOPM) driven by a sawtooth radio frequency waveform. This modulation induces a deterministic frequency shift while preserving the temporal shape of the photons.

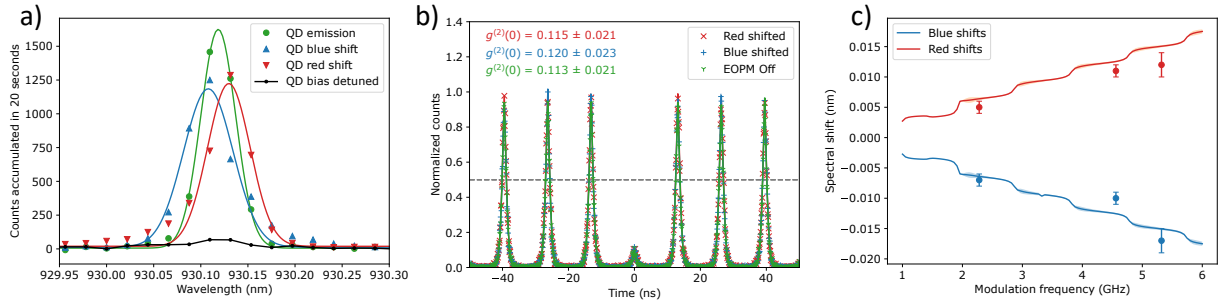


Fig. 1: a) Quantum dot (QD) emission spectra. b) Time-histograms, $g^{(2)}(\tau)$. c) Tunable spectral shift by varying the modulation frequency. Points represent experimental data, while solid lines represent experimentally realistic simulations. In all the plots a consistent color scheme is used: green trace indicates no frequency shift (EOPM off), while red (blue) represents downward (upward) frequency shift.

The spectra before and after the frequency shift are shown in Fig. 1(a), where a clear spectral shift can be observed. The measured frequency shift is ± 3.5 GHz (± 0.01 nm). The experimentally determined purity of the source is 88.3%. The second-order correlation function $g^{(2)}(0)$ values for unshifted, red-shifted, and blue-shifted photons remained consistent within experimental uncertainties, as displayed in Fig. 1(b). By adjusting the modulation frequency, the spectral shift was demonstrated to be tunable, as illustrated in Fig. 1(c). Additionally, Hong-Ou-Mandel interference experiments showed that the electro-optic frequency shift preserves the indistinguishability.

In summary, we demonstrate a robust method for achieving stable and tunable spectral shifts of single photons emitted by QDs using electro-optic phase modulation. This approach preserves the purity and indistinguishability of the photons. The deterministic and scalable nature of this technique makes it a promising solution for various applications in quantum photonics.

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A High-Data-Rate Fermionic Quantum Simulator in Optical Lattices

Tue – 38

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The study of strongly correlated fermionic systems lies at the core of some of the most interesting problems in material science, quantum chemistry, and particle physics; however, simulating many fermions presents an outstanding computational challenge — even with qubit-based quantum computers of near-term architectures. Fermionic quantum simulators, where fermionic statistics are built-in on a hardware level, offer a promising alternative. Here, we present recent results from our new quantum gas microscope of fermionic lithium in optical lattices. Leveraging a compact chamber design, deep optical trap loading, and rapid cooling, we accelerate state preparation to achieve high data rates. Our system features robust single-site, spin-resolved detection, which enables the extraction of a wealth of information for the analog simulation of the Fermi-Hubbard model. Additionally, with the development of single-fermion gates via addressed Raman rotations and two-fermion gates through controlled collisions in optical superlattices, we aim to pave the way toward fermionic quantum information processing.

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Broadband cavity-ringdown spectroscopy with comb-based Fourier-Transform Spectrometer

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Cavity-ringdown spectroscopy (CRDS) is a well-established technique in modern spectroscopy, known for its exceptional sensitivity and distinctive features like calibration-free operation and resilience to fluctuations in light intensity. These advantages enable precise detection of weak absorption lines. However, conventional continuous-wave (cw) laser-based approaches often involve sequential acquisition of spectral elements, which makes experimental data determination prone to temperature variations in the sample and extends acquisition times. This limitation highlighted the need for a broadband, parallel acquisition method capable of delivering multiplexed spectra with equivalent resolution and sensitivity.

The initial broadband CRDS demonstration was conducted by Engeln and Meijer [1], utilizing pulsed dye lasers alongside step-scan time-resolved Fourier transform spectrometers. Despite this advancement, challenges in resolution and acquisition time restricted wider adoption. Later, Thorpe et al. [2] introduced the use of optical frequency combs for broadband CRDS, refining spectral photography approach with improved sensitivity. In 2022, two innovative techniques emerged to enhance resolution and speed: combining CRDS with dual-comb interferometric detection [3], and employing time-resolved Fourier transform spectroscopy using a single optical frequency comb [4]. Very recently Liang et al. [5] demonstrated a related method with mid-infrared experiments.

This work introduces an approach based on direct frequency comb Fourier transform spectroscopy, inspired by Dubroeuq and Rutkowski [4], with updates incorporating recent advancements [6]. Key improvements include a redesigned frequency stabilization method allowing extended extinction of comb light without losing the comb-cavity lock. A cw-laser serves as an intermediary between the comb and the cavity.

The experimental setup's performance was validated through absorption measurements of CO mixed with Ar, showcasing high signal-to-noise ratios and confirming the impact of speed-dependent effects on absorption line profiles.

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Relativistic effects and compensation of initial conditions in atom interferometers

Tue – 40

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Light-pulse atom interferometry with quantum gases is used in high-precision metrology for quantum-based inertial sensing and fundamental physics tests in ground-based laboratories as well as in space. Their current use covers over a wide range of topics such as measuring gravitational acceleration, gravitational gradients, rotation as well as measuring the fine structure constant [1], testing Einstein's equivalence principle [2], or searching for physics beyond the Standard Model. Nowadays, there are even ambitious proposals for gravitational-wave and dark-matter detectors using light-pulse atom interferometers, where some prototypes are already under construction [3].

To achieve sufficiently high precision for these kinds of experiments, a large spacetime area must be covered by the interferometer, relying either on advanced techniques like large momentum transfer or on long interrogation times during the free propagation period of the interferometer. Both approaches lead to large spatial arm separation of a two-arm-interferometer and raise the question whether the finite propagation times of light pulses [3] between the two arms become important as seen in figure 1. All relativistic effects of similar order have to be taken into account for a consistent analysis of the total interferometric phase.

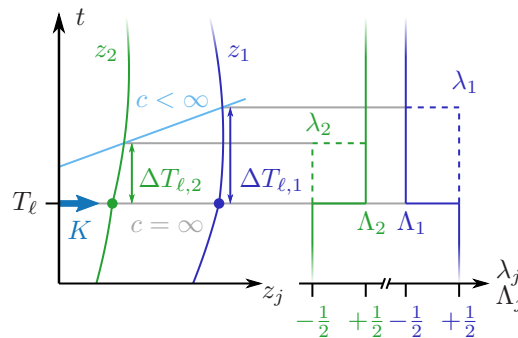


Fig. 1: Two interferometer arms are plotted on the left hand side. In the case of infinite speed of light, the laser interacts simultaneously with both interferometer arms. Thus, the state response functions $\Lambda(t)$, telling whether the atom is in the ground ($-1/2$) or excited ($+1/2$) state, change values at the same time on the right hand side. In the case of finite speed of light, the interaction of the light with the atoms is delayed by some arm dependent time.

Therefore, the mass defect of an atom between the ground state and the excited state has to be considered as well. It leads to different Compton frequencies depending on the internal state of the atom and thus to a shift of the interferometric phase. The third considered effect deals with the gravitational effect on the diffracting light beam as well as the gravitational acceleration of the atom. The latter requires chirping the diffracting laser frequencies in order to be on resonance with the atomic transition during the entire interferometric sequence and to compensate for the Doppler shift induced by the gravitationally accelerated atom.

All effects are discussed within a single framework that is independent of the explicit geometry of the two-arm-interferometer and the diffraction mechanism used. The resulting expression is applied to a gravimeter in the Mach-Zehnder-interferometer for single-photon, Bragg- and Raman-two-photon-transitions, respectively. In the case of transitions on resonance and chirping, where gravity is perfectly canceled, we give exact expressions for the observed interferometric phase shift and show that the effect of the finite speed of light is suppressed. Furthermore, we present a compensation method for the remaining dependence on the initial velocity of the atomic cloud.

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Improving the Entanglement Fidelity for a $^{40}\text{Ca}^+$ Quantum Node

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Entanglement between remote quantum systems is a cornerstone for distributed quantum computing and quantum networks. The ion-cavity system is a promising candidate for achieving remote entanglement, as it combines the long coherence times of ions with a highly controllable photonic interface. In 2023, we reported entanglement between two $^{40}\text{Ca}^+$ ion-cavity systems separated by 230 m [1]. In that work, entanglement between an ion's electronic state and a photon's polarization state was generated via a bichromatic Raman scheme involving the transitions $4^2S_{1/2} \leftrightarrow 4^2P_{3/2} \leftrightarrow 3^2D_{5/2}$ [2], as depicted in Fig. 1(a). However, the entanglement fidelity was limited due to single-photon distinguishability caused by the scattering of the ion back to its initial state. To overcome this limitation, we propose a Raman scheme in which the initial state is chosen as $3^2D_{3/2}$, as illustrated in Fig. 1(b). By selecting this initial state, we reduce the probability of decaying back to the original state compared to the previous scheme. Through simulations, we show that this scheme significantly suppresses the detrimental effects of scattering on single-photon indistinguishability and improves the entanglement fidelity between two $^{40}\text{Ca}^+$ ion-cavity systems.

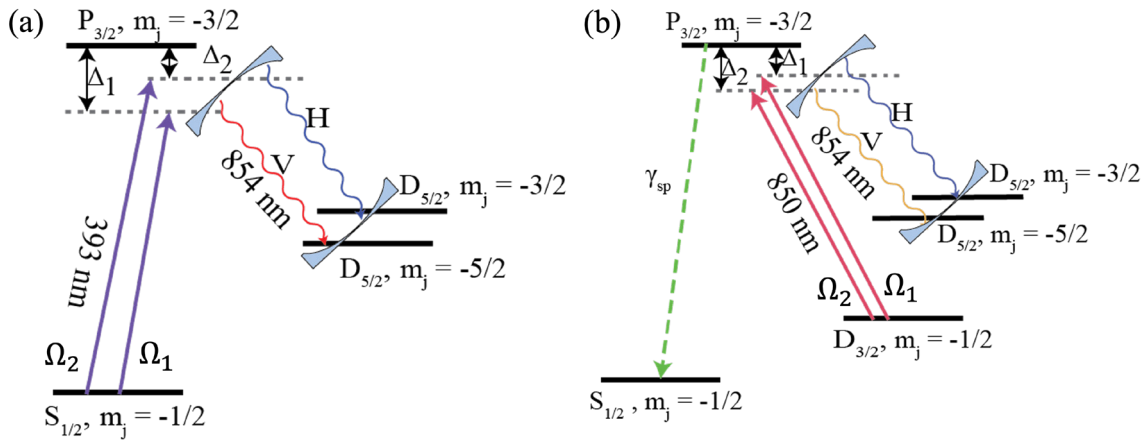


Fig. 1: (a) Energy-level diagram of the Raman scheme from Refs. [1,2]. A bichromatic 393 nm Raman pulse (blue arrows) with Rabi frequencies Ω_1 , Ω_2 and detunings Δ_1 , Δ_2 couples state $|S_{1/2}, m_j = -1/2\rangle$ to states $|D_{5/2}, m_j = -5/2\rangle$ and $|D_{5/2}, m_j = -3/2\rangle$ via two cavity polarization modes H and V , generating a single cavity photon. (b) The Raman scheme discussed here. A bichromatic pulse couples state $|D_{3/2}, m_j = -1/2\rangle$ to states $|D_{5/2}, m_j = -5/2\rangle$ and $|D_{5/2}, m_j = -3/2\rangle$ to suppress the scattering effect.

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PT symmetry breaking in ^{129}Xe under complex gradients**L.M. Ellis^{*1}, M. Jayaseelan², V. Guarrera², G. Quick³, B. Steele³, L. M. Rushton¹, J. D. Zipfel¹, P. Bevington¹, W. Chalupczak¹**¹National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, United Kingdom²School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom³INEX Microtechnology Ltd., Herschel Annex, Kings Road, Newcastle upon Tyne, NE1 7RU, United Kingdom

Miniature, wafer-fabricated vapour cells offer an interesting platform to study Parity-Time (PT) symmetry-breaking in ^{129}Xe spectra, where interactions with a dense, optically polarised Cs vapour and N_2 buffer gas produce novel effects. In spatially homogeneous conditions, the Bloch-Torrey equation, which governs the diffusive motion of ^{129}Xe spins, is PT symmetric. Its stationary solution gives a set of delocalised modes with the same frequency and distinct relaxation rates. Past some critical inhomogeneity, which defines an exceptional point (EP), the system transitions to a symmetry-broken state; the relaxation rates are now degenerate, and the frequencies are distinct [1]. Previous realisations of PT symmetry breaking in diffuse atomic systems have used external coils to introduce linear magnetic field gradients [2]. In our work, novel complex gradients in magnetic field and relaxation rate are created through inhomogeneous polarisation of Cs. This offers a series of parameters, including vapour temperature, pump power and buffer gas pressure, to tune the system between the symmetric and asymmetric phases. We systematically study these parameters and offer regimes where the symmetry-broken modes can be exploited to enhance system performance for application to a range of quantum technologies.

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Efficient excitation of a three-level atom by a propagating two-photon field

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We considered the problem of optimal excitation of a three-level atom of ladder configuration by propagating light in the two-photon state [1]. The applied atom-light interaction model is based on the Wigner-Weisskopf approximation. Thus the model is formulated within the following assumptions: a flat coupling constant, rotating wave approximation, and the extension of the lower limit of integration over frequency to minus infinity [2, 3]. We analyze the probability of two-photon absorption by the atom using the analytical formula determined in [4] that was obtained by making use of quantum trajectories [2, 5]. We characterized the properties of the optimal two-photon state that excites an atom perfectly, i.e. with probability equal to one. The spectro-temporal shape of the optimal state of light is determined by the lifetimes of the atomic states, with the degree of photonic entanglement in the optimal state depending on the lifetime ratio. In consequence, two distinct interaction regimes can be identified in which the entanglement of the input state of light has a qualitatively different impact. We show that photon entanglement plays a fundamental role in the optimal excitation of a system by two-photon light.

As the optimal states may be challenging to prepare in general, we compare the results with those obtained for photon pairs that can be generated in the laboratory. We optimize the parameters of these two-photon light states to achieve the maximum probability of two-photon absorption for the atomic system. We present the role of entanglement and resonances in the atom excitation process, and show how destructive and constructive light interference affects excitation of the atom. Part of the obtained results has already been published and presented in [6]

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Stabilization of spin mixtures and sub-microsecond Feshbach resonance probing in dipolar Bose gases

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Mixtures of ultracold gases with long-range interactions are expected to open new avenues in the study of quantum matter. Natural candidates for this research are spin mixtures of atomic species with large magnetic moments. However, the lifetime of such assemblies can be strongly affected by the dipolar relaxation that occurs in spin-flip collisions. Here we present experimental results for a mixture composed of the two lowest Zeeman states of ^{162}Dy atoms, that act as dark states with respect to a light-induced quadratic Zeeman effect. We show that, due to an interference phenomenon, the rate for such inelastic processes is dramatically reduced with respect to the Wigner threshold law. Additionally, we determine the scattering lengths characterizing the s -wave interaction between these states, providing all necessary data to predict the miscibility range of the mixture, depending on its dimensionality [1].

Moreover, we exploit this spin-dependent light shift to achieve precise control and manipulation of Feshbach resonances on sub- μs timescales. This approach enables us to directly displace and probe resonance features with unprecedented temporal resolution. In particular, loss features in Feshbach resonances stem from three-body recombination processes, where two particles form a dimer that relaxes to a lower bound state via interactions with a third auxiliary particle. Following a quench of the s -wave scattering length, this process is amplified by the rapid emergence of three-body correlations occurring over short timescales. By capturing the early onset of these losses, our technique provides valuable insights into the non-equilibrium dynamics of the strongly interacting Bose gas. Additionally, it enables precise measurements of dimer energies associated with the intricate Feshbach spectrum of ^{162}Dy , both below and above the scattering threshold [2].

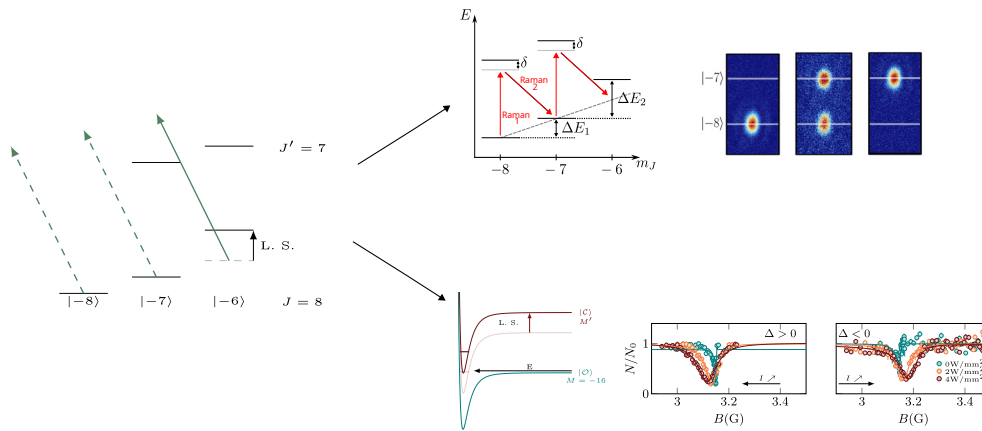


Fig. 1: Left: Tensorial polarizability of dysprosium used to generate spin-dependant light shifts. Top right: the spin-dependant light shifts introduces an effective quadratic Zeeman effect. The transition between the two lowest Zeeman sublevels, that are dark states, can then be addressed by a Raman transition to produce a spin mixture. Bottom right: the energy of the bound state of a Feshbach resonance's closed channel can be shifted by the spin-dependant dressing, thereby shifting the resonance's pole in magnetic field. The loss feature associated with a Feshbach resonance is shifted in presence of the laser beam.

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Building a Quantum Gas Microscope for Simulation with Programmable Optical Lattices

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Ultracold atoms in optical lattices offer a versatile platform for simulating and probing strongly correlated quantum matter. While quantum gas microscopy techniques have enabled unprecedented single-site resolution, some of the remaining challenges of the field are still posed by rigid lattice configurations and slow cycle times.

Here, we present our ongoing efforts to tackle these issues by designing and building a next-generation quantum gas microscope for fermionic and bosonic lithium atoms. Our approach relies on atom-by-atom assembly in small lattice systems by means of auxiliary optical tweezers, combined with all-optical cooling techniques to facilitate sub-second experimental cycles. The holographic projection of a blue-detuned, short-spacing lattice will provide reconfigurability and fast dynamics, leading to diverse research avenues for our new project, from the simulation of phases of matter predicted by the Fermi- and Bose-Hubbard model to topological phases and frustrated systems with unconventional lattice shapes.

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Generalized dressed atom approach

Tue – 47

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The dressed atom approach provides a tool to investigate the dynamics of an atom-laser system by fully retaining the quantum nature of the coherent mode. In its standard derivation [1], the internal atom-laser evolution is described within the rotating-wave approximation, which determines a doublet structure of the spectrum and the peculiar fluorescence triplet in the steady state. However, the rotating wave approximation may fail to apply to atomic systems subject to femtosecond light pulses, light-matter systems in the strong-coupling regime or sustaining permanent dipole moments.

This work aims to demonstrate how the general features of the steady-state radiative cascade are affected by the interaction of the dressed atom with propagating radiation modes [2]. We will analyze how these features depend on the parameters characterizing the dressed eigenstates in arbitrary atom-laser dynamics, given that a set of general hypotheses is satisfied. We will clarify the general conditions in which a description of the radiative cascade in terms of transition between dressed states is self-consistent. We will provide a guideline to determine the properties of photon emission for any atom-laser interaction model, which can be particularly relevant when the model should be tailored to enhance a specific line. The general results will be applied to the case in which a permanent dipole moment acts as a source of low-energy emission, whose frequency is of the order of the Rabi coupling [3].

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Poster session

Thursday



Poster sessions

Thursday



Self-nulling 2D biplanar coils for cold atom magnetometry

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Spinor Bose-Einstein condensates (SBECs) are ideal candidates for high-spatial-resolution optical magnetometry, demonstrating sensitivities of up to $\sim 50 \text{ fT}/\text{Hz}^{1/2}$ at the few- μm scale [1-3]. In this work, we aim to study the viability of shielding an SBEC comagnetometer with a layer of mu-metal to reduce magnetic field noise.

The first step towards an SBEC is a magneto-optical trap (MOT) which employs a spatially varying magnetic field and six counter-propagating optical molasses beams to confine and cool the atoms down to the Doppler limit. Most commonly, a pair of coils with counter-propagating currents in a so-called anti-Helmholtz configuration produces the necessary magnetic field gradient. However, this is not a viable solution when the system is placed inside a magnetic shield, as the stray field near the coils would polarize the mu-metal, making it ineffective. Instead, we must design alternative current configurations with which the magnetic field is effectively nulled around the coils [4].

We propose a configuration in which the current loops are confined to two parallel planes. The coils generate the desired magnetic field gradient between the planes. Each plane features four openings, granting access to the optical molasses beams. We have designed the current loops with *bfieldtools* [5] so that the field nulls out at a distance from the center of the planes < 2 the planes' dimensions. Additionally, this current loop arrangement gives freedom to optical access from different angles to additional optical beams used to probe, image, and trap the atoms.

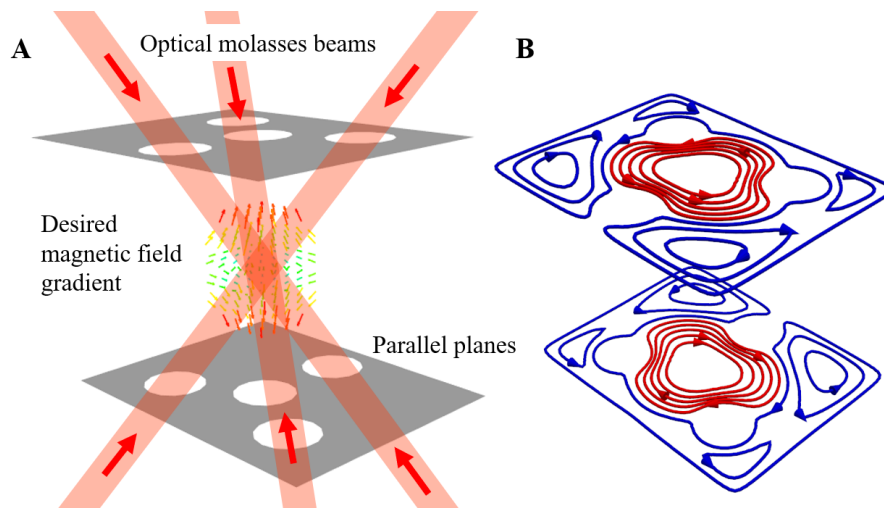


Fig. 1: Coil configuration. The desired magnetic field gradient between the planes, represented in A, is obtained by the current loops shown in B. The optical molasses beams going through their respective holes are also represented in A. An additional hole at the center of the plane grants further access to the SBEC, allowing for Stern-Gerlach or time of flight measurements.

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Optically Connected Nuclear Spin Microprocessors

Thu – 3

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Silicon Vacancy (SiV) color centers in diamond hold promise for enhancing quantum communication systems. SiVs feature atom-like optical transitions, which enable high-fidelity interactions between photons and a long-lived electron spin. The inversion symmetry of the SiV protects its optical transition from electrical noise, making it suitable for integration into QED structures in the nanophotonic cavity. Nevertheless, SiV color centers require operation at low temperatures and the application of strong radio frequency fields to manipulate nuclear spins.

In this work, we introduce a platform that combines superconducting nuclear magnetic resonance coils with nanophotonic structures designed to function at millikelvin temperatures, thereby paving the way for advances in quantum networks utilizing multiqubit SiV-based systems.

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Floquet-Liouville approach to efficient solving non-equilibrium steady states for Rydberg radio frequency receivers

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Multi-level atoms, e.g. excited to Rydberg states, present many unique opportunities, but present several challenges for numerical treatment of their interaction with multiple laser fields. In hot-atom systems this is further aggravated by the necessity to include Doppler broadening. Further challenges arise if the system is time-dependent, as the system then doesn't have a strict steady-state solution. Our study presents a numerically efficient approach to solving non-equilibrium steady states, focusing on fractured atomic loops, as exemplified by Rydberg-atom microwave sensing protocols. By manipulating terms within the master equation and applying Fourier expansion of Floquet-Lindblad modes, we uncover new insights into the control and coherence of atomic states under periodic driving, resulting from fracture [1]. The results are particularly relevant for superheterodyne Rydberg sensors [2], where the main question is the efficient transfer of modulation from a weak microwave signal field to light. These findings enhance our understanding of quantum dynamics in Floquet systems and offer potential applications in modelling quantum communication, sensing and transduction protocols [3].

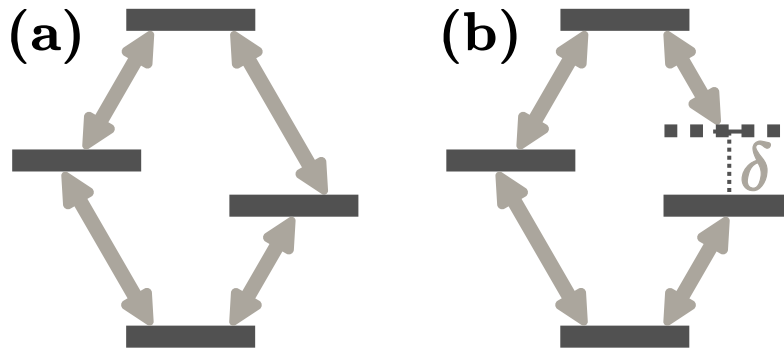


Fig. 1: A resonant (a) and a fractured (b) loop. Evolution of the resonant setup finishes in steady-state, evolution of fractured setup results in non-equilibrium steady-state.

References should appear at the end of the abstract, in the order in which they are referenced in the body of the text. Please refer to the examples below for the presentation of the references [1-4].

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Calculating frequency-filtered N -photon spectra of solid-state quantum emitters

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Field correlation functions are commonly used to characterise light emitted by quantum sources. Yet, their calculation is most often based on the quantum regression theorem (QRT), which imposes Born and Markov approximations on the evolution of two-time correlation functions. However, these approximations do not hold for solid-state quantum emitters, such as semiconductor quantum dots (QD), where the influence of the additional phonon environment of the lattice has to be considered [1]. Moreover, spectral filtering, often used to select the required emission frequencies, introduces further complexity in the calculations. Since solid-state emitters are promising candidates for future quantum technologies, it is therefore of high relevance to study techniques for calculating photon correlations beyond the QRT.

The recently developed *sensor method* [2] provides a conceptually simple and efficient framework for calculating frequency-filtered correlation functions. In our work [3] we extend this technique to the case of solid-state quantum emitters interacting with a vibrational environment, see Fig. 1. This allows us to obtain N -photon spectra of a resonantly-driven QD. We show that our method, even within a weak-coupling approximation for the phonon environment, is capable of correctly accounting for phenomena not captured by the standard QRT calculation, such as the phonon sideband [1]. Within the regime of validity of the weak-coupling approximation, our results are found to be in an excellent agreement with a numerically-exact calculation using a sophisticated TEMPO method [4]. Furthermore, we compute for the first time the *two-photon spectrum* of a QD under the influence of the phonon environment. This calculation reveals the cross-correlations between the different parts of the emission spectrum, including correlations between the phonon sideband and the peaks of the Mollow triplet. We additionally find that structure of correlations between the three peaks of the Mollow triplet is preserved in the emission from the phonon sideband.

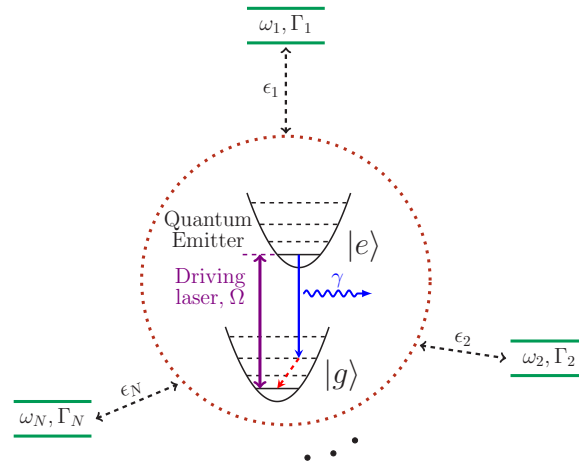


Fig. 1: A schematic diagram of the sensor method for a solid-state quantum emitter [3]. The emitter is a two-level system driven by a continuous-wave laser with Rabi frequency Ω . The energy levels ($|g\rangle$, $|e\rangle$) of the emitter are affected by its interaction with lattice vibrations. N sensors, modelled as two-level systems with energy gaps ω_i and decay rates Γ_i , are weakly coupled to the emitter. Frequency-filtered photon correlation functions are obtained from populations of the sensors.

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A case study on Doppler heating using Rydberg Doppler velocimetry

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Accurate measurement of velocity distributions is crucial for characterizing cold atomic clouds. We have developed a Doppler velocimetry technique based on Rydberg spectroscopy. We access Rydberg states by two-photon excitation, where the atoms are subsequently ionized, and the resulting ions are collected. The key idea is that the Doppler shift in the absorption frequency of the Rydberg transition directly encodes the atomic velocity, allowing us to extract detailed velocity distributions with minimal perturbation to the system. Our Rydberg-based velocimetry offers several advantages over conventional methods [1,2]: high spectral resolution with low signals, applicability across a wide range of cloud temperatures (limited only by the linewidths of the excitation lasers), locality of the measurements, and the ability to map both position distribution and momentum-position correlations through arrival-time analysis of the ions [3].

To demonstrate the capabilities of our technique, we study the Doppler heating mechanism. We observe the appearance of bimodality in the velocity distribution under a range of positive laser detuning and heating times, shown in Figure 1. This behavior corresponds to the formation of spatially distinct atomic clusters with unique momentum-position correlations, which are different from free expansion dynamics. In a magneto-optical trap laser setup, the cluster atoms form an expanding cubic lattice as the heating time increases. Our experimental findings are corroborated by theoretical numerical simulations, validating the performance of our approach. This study not only provides insights into the Doppler heating mechanism but also establishes a tool for future research of cold atomic cloud dynamics.

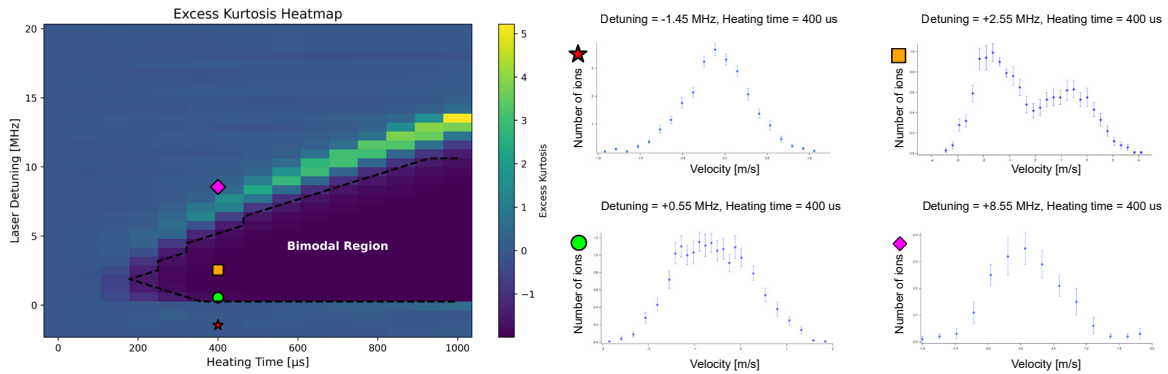


Fig. 1: Theoretical heatmap of excess kurtosis in the velocity distribution based on laser detuning and heating time, with marked points linked to experimental plots.

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Spontaneous emission of dipolar adatoms near SSH chains

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The light-matter interaction in one-dimensional structures offers promising avenues for nanoscale photonics and quantum technologies. This study focuses on a two-level atom in the vicinity of Su-Schrieffer-Heeger (SSH) chains, modeling them in a tight-binding framework [1]. The adatom, modeled as a dipole source, is optically coupled to the chain. The primary quantity investigated is the imaginary part of the Green's function at the dipole's position, which characterizes the spontaneous emission rate of the dipolar emitter as modified by its proximity to the SSH chain [2].

In the first phase of the study, we analyze a one-dimensional metallic chain, exploring the impact of the local environment and symmetry-breaking effects by identifying two distinct interaction regimes based on the adatom-chain distance. As the adatom-chain distance varies, the adatom can enter a curved nodal plane near the chain's edge, resulting in a significant suppression of the spontaneous decay rate. The position and curvature of these nodal planes are examined for various resonant modes and chain lengths.

Subsequently, we parametrically introduce dimerization into the metallic chain, transforming it into a semiconducting chain by opening a bandgap. As the chain transitions from metallic to semiconducting, the impact of electron interactions is suppressed. The states in close vicinity of either side of the bandgap exhibit heightened sensitivity to the dimerization process, showing significant changes in the local density of states and charge redistribution across the two sublattices. This redistribution significantly alters the transition dipole moments involving these states causing modification of absorption spectra of the chain and the spontaneous decay rate of the adatom. Furthermore, we identify the distinct mechanisms governing spontaneous emission enhancement in metallic and semiconducting chains, demonstrating the impact of electron interactions in shaping these processes.

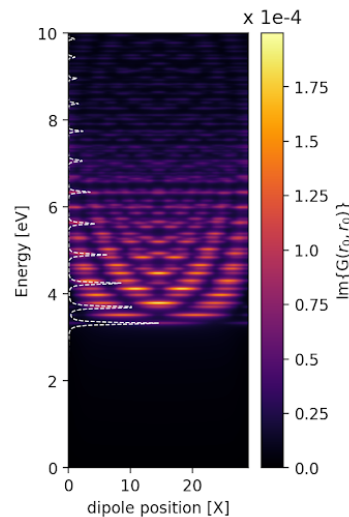


Fig. 1: Heatmap of the imaginary part of the Green's function, $\text{Im}\{G(\omega, r_0, r_0)\}$, at the dipole source position for a 30-atom long dimer chain (dimerization parameter = 0.3). The plot shows the dipole's varying positions along the chain's length (x-direction), with a constant chain-dipole distance of $y = 5 \text{ \AA}$. The white dotted line represents the absorption spectrum of the same structure under plane wave illumination. Note: For comparison, the energy axis of the absorption spectrum and $\text{Im}\{G(\omega, r_0, r_0)\}$ are aligned, but the absorption spectrum's horizontal axis represents the absorption cross-section, which is not shown in the figure.

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Towards the formation of ultracold highly polar CsAg and KAg molecules**Jorge Mellado Muñoz^{*}, Jakub Pawlak, Mariusz Semczuk[†]**

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Silver (Ag), which can be cooled with methods similar to those used with alkali atoms due to their similarities, presents interesting properties that can be exploited. Firstly, it presents a metastable state accessible by a two-photon transition, which can be used as a clock state [1]. Secondly, some Ag-alkali molecules, in particular KAg and CsAg, can achieve electric dipole moments nearing 10 D in the absolute roto-vibrational ground state. For CsAg, dipole moments exceeding 13 D can be attained in higher vibrational levels of the ground state potential, requiring only 0.3 kV/cm to fully polarize the sample [2], making the effects of dipole-dipole interactions an order of magnitude stronger than any other alkali molecule. Thus, Ag-alkali molecules are an excellent platform for quantum simulations for systems in which long-range dipole-dipole interactions dominate. Our long-term goal is the realization of a setup able to produce ultracold CsAg and KAg molecules.

In our planned implementation, K and Cs are loaded into 3D magneto-optical traps (MOTs) from a shared 2D MOT, while a separate 2D MOT is used for loading the 3D MOT of Ag. Currently, we are working on the development of the Ag 2D MOT that will be used to generate a transversally cooled beam of Ag atoms. 2D MOTs are widely used in alkali atoms experiments. The vapor pressure of some alkali atoms at or close to room temperature is usually sufficient to obtain the required flux of atoms from the 2D MOT to load a 3D MOT. In the case of atomic species that require few hundreds of degrees to achieve this, such as Li or Yb, ovens are used in combination with 2D MOTs or Zeeman decelerators to obtain the desired atom flux. In this regime, the hot atoms can easily coat the windows of the experimental setups. To avoid this, the oven and 2D MOT can be placed in separate chambers. A more elegant solution, and the one chosen for our setup, is to build a high-temperature dispenser with an aperture directed away from the windows of the chamber [3]. This will be the first Ag setup to use a 2D MOT, allowing for an excellent control over the atom flux in a very compact format.

Alongside the development of the Ag MOT, we are working in the spectroscopy of the clock state and cooling transition of Ag using a frequency comb. This will provide invaluable information about the hyperfine structure of the cooling transition that can be used for the realization of more elaborate laser cooling schemes, such as gray molasses or dark MOT. The detailed spectroscopy of the clock state will be useful for the development of Ag as an optical clock platform and for the possibility of cooling Ag atoms via this narrow transition.

In the future, we will perform evaporative cooling in a dipole trap of both species, Ag and Cs, and we will study the Feshbach resonances between the two species. These resonances will be used to form weakly bound CsAg molecules.

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Testing the universality of three-body interactions near narrow Feshbach resonances

Thu – 9

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We study properties of Efimov states and explore their dependence on the strength of the underlying Feshbach resonance. Within a two-channel model for the interatomic interactions, we calculate the energies of the Efimov ground and excited states to test the van der Waals universality expected for strong (broad) Feshbach resonances. By varying the position and strength of the two-body coupling between the channels, we modify the strength/width of the Feshbach resonance, as measured by the s_{res} parameter [1]. Investigating across a range of Feshbach resonance widths, we showcase the appearance of non-universal behavior of the Efimov trimer in the ground and excited states, likely emergent from a repulsive interaction in the atom-dimer channel, which appears for narrow resonances [2].

The interplay between the length-scales describing the short-range, exchange, and the van der Waals interaction across a series of alkali-metal, homonuclear samples is likely an important factor determining the universal behavior of the Efimov spectrum. Thus, we compare the Efimov spectra dependence on the s_{res} parameter for systems with varying strength of the Feshbach resonance across a range of atomic species [3]. Interestingly, we also show how the non-universal behavior changes upon switching the resonance across many closed-channel bound states, which gives insights about the nature of the repulsive interaction and provides a way to measure the influence of the coupling position on the non-universal behavior of the resonance.

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Development of a variable-geometry multiplexed strontium optical atomic clock

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Over the past twenty years, experimental platforms based on alkaline earth atoms in optical lattices have rapidly advanced, with strontium emerging as a key atomic species in a wide range of state-of-the-art cold-atom quantum technologies, including optical atomic clocks, quantum computers, and quantum simulators. The most recent realization of strontium optical lattice clock has achieved remarkable accuracy on the level of 10^{-19} [1], making strontium a unique platform for metrology and precision measurements, as well one of the leading candidate elements for the redefinition of the second [2]. Meanwhile, in recent years, optical tweezers have expanded the capabilities for single optical qubit control and detection, opening new research avenues in quantum simulation, quantum computing, and metrology.

In our laboratory, we are developing the first strontium-based optical atomic clock in Croatia. The goal is to produce a variable-geometry multiplexed lattice clock by creating an array of 1D lattices at the magic wavelength. This configuration combines the unique flexibility of techniques employed in optical tweezers with the high accuracy of 1D optical lattice clocks. Here, we report on the current state of our experiment and offer an outlook for our clock.

Additionally, we present our latest published work [3] - the first direct measurement of the lifetime of the $5s5p^1P_1$ state of ^{88}Sr , achieved through time-correlated single-photon counting of laser-induced fluorescence in a hot atomic beam. One of the primary sources of uncertainty in strontium lattice clocks is the blackbody radiation (BBR) shift, which arises due to the substantial differential polarizability between the clock states. This shift is calculated using available spectroscopic data and depends on the Einstein coefficients (A) for transitions between higher-lying states and the clock states. For the ground $5s^2S_0$ state, over 90% of the total polarizability comes from the $5s5p^1P_1$ state, meaning an accurate and precise determination of the Einstein coefficient $A(5s5p^1P_1 \rightarrow 5s^2S_0)$ is essential for reducing the uncertainty in strontium optical lattice clocks.

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A Warm Rydberg Atom-Based Wi-Fi Signal Receiver

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Rydberg atoms exhibit both remarkable sensitivity to electromagnetic fields making them promising candidates for revolutionizing field sensors and, unlike conventional antennas, they neither disturb the measured field nor necessitate extensive calibration procedures. In this study, we propose a receiver design for data-modulated signal reception near the 2.4 GHz Wi-Fi frequency band, harnessing the capabilities of warm Rydberg atoms. Our focus lies on exploring various quadrature amplitude modulations and transmission frequencies through heterodyne detection. Additionally, we delve into analyzing communication errors using Voronoi diagrams and evaluating the communication channel capacity across different modulation schemes.

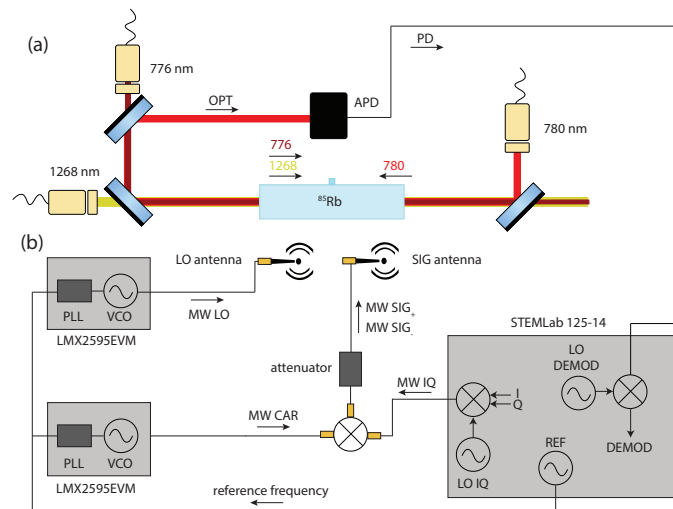


Fig. 1: (a) Optical part of the experimental setup. APD - avalanche photodiode, OPT - optical signal, PD - photodiode signal (b) The electronic part of the experimental setup. PLL - phase-locked loop, VCO – voltage-controlled oscillator, LO - local oscillator, MW - microwave, CAR - carrier signal, DEMOM - demodulation signal.

The main goal of the experiment is to receive data encoded into the signal SIG through modulation of the MW field, using the quadrature amplitude modulation (QAM) scheme[1]. In this experimental realisation, the signal is generated from the amplitude-modulated I (in-phase) and Q (quadrature) components shifted in phase by $\frac{\pi}{2}$. The components define two-dimensional IQ space, in which QAM can be described as an even symmetrical points distribution around the origin. One of the more important parameters of data transmission is the symbol error rate (SER), defined as the probability of incorrectly receiving symbols. As the noise for both the I and Q components is Gaussian, we calculate SER by integrating Gaussian probability distribution over a specific area of the IQ space. The integral areas are defined by the structures known as the Voronoi cells[2,3]. The diagram is created from seed points, which in this case are mean positions received symbols, based on which the Voronoi cell limits are calculated.

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High-dimensional quantum key distribution with resource-efficient detection

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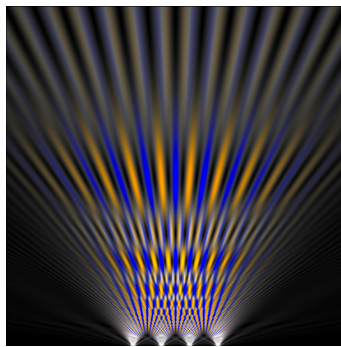
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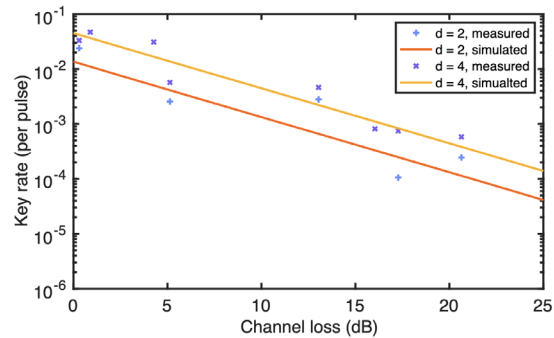
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While quantum key distribution (QKD) based on two-dimensional (qubit) encoding is a mature, field-tested technology, its performance is lacking for many cryptographic applications. High-dimensional encoding for QKD enables increased achievable key rates and robustness as compared to the standard qubit-based systems. However, experimental implementations of such systems are more complicated, expensive, and require complex security analysis [1,2]. Additionally their implementation may introduce vulnerabilities such as basis-dependent detection probability unaccounted for in the security proof [3]. Here, we present a proof of principle high-dimensional time-phase BB84 QKD experiment using only one single-photon detector per measurement basis [4]. States are prepared by electro-optic modulation of a continuous wave laser light. Decoy states are prepared by changing the settings of two amplitude modulators. Measurements in the key generation basis are realised via time-resolved niobium-nitride superconducting nanowire single-photon detectors. We employ the temporal Talbot effect to detect QKD symbols in the control basis [5]. Experimentally-obtained key rates for the two-dimensional and four-dimensional case, including in an urban fibre network, show the advantage of high-dimensional encoding in the high measurement error regime. We present a comparison of the secret key rates obtained from two different security proofs: standard decoy-BB84 d -dimensional protocol and new tunable beamsplitter modification proposed in [3]. The latter treatment closes the basis-dependent probability loophole and thus provides increased security by relaxing the assumptions on the implementation of the protocol. Our results contribute to the discussion of the benefits of high-dimensional encoding and highlight the impact of security analysis on the achievable QKD performance.



(a)



(b)

Fig. 1: (a) Temporal Talbot carpet shows dependence of the relative phases of four time-bin pulses. Horizontal axis represents time and vertical axis represents applied dispersion with Talbot dispersion in the middle. Blue and orange fringes correspond to superpositions with equal phases and alternating $0, \pi$ phases respectively. (b) Experimentally obtained key rates for the 2- and 4-dimensional decoy-BB84 protocol security proof based on the measurements in the urban network.

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Quantum Metrology in the Ultrastrong Coupling Regime of Light-Matter Interactions: Leveraging Virtual Excitations without Extracting Them

Thu – 14

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Virtual excitations, inherent to ultrastrongly coupled light-matter systems, induce measurable modifications in system properties, offering a novel resource for quantum technologies. In this work, we demonstrate how these virtual excitations and their correlations can be harnessed to enhance precision measurements, without the need to extract them. Building on the paradigmatic Dicke model, which describes the interaction between an ensemble of two-level atoms and a single radiation mode, we propose a method to harness hybridized light-matter modes for quantum metrology. Our results not only highlight the potential of virtual excitations to surpass classical precision limits but also extend to a broad range of ultrastrongly coupled systems.



Thu – 15

Floquet engineering of Bose mixture with interactions of any shape**D. Włodzyński^{*1}, K. Sacha¹**¹ Atomic Optics Department, Jagiellonian University, ul. Gołębia 24, 31-007 Kraków, Poland

We have analyzed a system of ultracold bosonic atoms on a one-dimensional ring with periodically modulated strength of contact interactions. For high driving frequency, the system in the resonant state is effectively described as a time-independent two-component Bose mixture. The shape of the effective intercomponent interactions is the same as the time dependence of the interaction strength in the initial problem. Therefore, one could use this procedure to simulate a Bose mixture with any intercomponent interactions using single-component Bose gas with appropriate driving. For example, by introducing disorder to the driving, one can obtain a system with Anderson localization in the relative motion of the atoms (so-called Anderson complexes).

Poster sessions

Thursday

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Programmable Fermionic Quantum Simulation on a Hybrid Tweezer-Lattice Platform

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Recent advances in probing complex many body systems allow us to raise incisive questions about their dynamics, which are classically hard to compute. Combining approaches from quantum information theory with state-of-the-art quantum simulation techniques can lead to new ways of characterizing itinerant quantum systems more generally. Programmable quantum simulation using ultracold fermions in optical lattices holds immense potential to address these investigations on many-body phenomena and non-equilibrium dynamics. However, the initialization of arbitrary quantum states has been a significant challenge along with the realisation of fast cycle times in such intricate systems. Latest developments on optical tweezer arrays offer a promising solution for creating programmable initial states. Leveraging the reconfigurability of tweezers, atoms can be arranged into arbitrary spatial configurations. When combined with optical lattices and site- and spin-resolved imaging techniques, this setting establishes a powerful platform for addressing challenging problems in quantum many-body physics [1], and exploring novel ideas such as measurements in random bases to probe many body states in a basis-independent manner [2,3].

In this presentation, I would like to demonstrate our recent work in this direction, wherein we realise these capabilities, showcasing the rapid and high-fidelity preparation of optical tweezer arrays, achieving deterministic trapping of fermionic atom pairs in the motional ground state of each tweezer. We demonstrate spin-dependent free-space imaging, efficient loading, and evaporation protocols, as well as deterministic control of atom numbers within the tweezer arrays. I would like to show our preliminary results that establish these techniques on a solid ground and the science that we explore with the use of tuneable lattice potentials followed by single-atom resolved imaging. As an outlook, I would like to discuss how these advancements expand the scope of quantum simulation beyond ground-state Hubbard physics, enabling exploration of quantum chemistry, and fermionic quantum information processing.

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Simultaneous Frequency Conversion and Spectral-Temporal Shaping of Single-Photon Pulses

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Long-distance transmission of quantum information between various systems, such as single-photon sources, quantum memories or matter-based quantum information processing units is hampered by disparate spectral-temporal properties of photons that can be efficiently emitted or absorbed by such systems. Quantum frequency conversion, i.e. low noise nonlinear optical frequency conversion, is an established method to address photon central frequency distinguishability. However, it does not address the issue of single-photon spectral bandwidth and timescale variations, which can range from single picoseconds to hundreds of nanoseconds.

Here we present a quantum interface device converting single-photon-level pulses simultaneously adjusting the central wavelength, bandwidth and pulse duration from those typical for a quantum dot (798 nm, 5 GHz, 150 ps) to standard fibre optical telecommunication channel (1300 nm, 100GHz, < 25ps), by driving nonlinear optical frequency conversion with a strong highly chirped pump pulses, effectively realizing a nonlinear time lens.

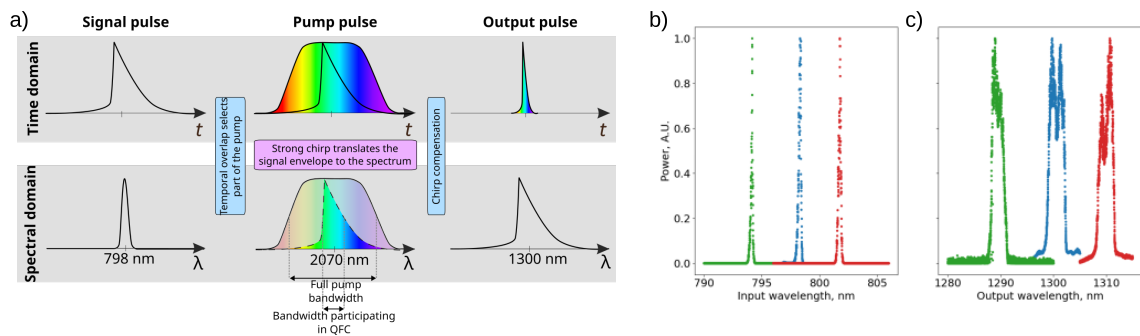


Fig. 1: (a) Pulse transformation. The signal pulse has narrow bandwidth and long duration as is typical for quantum dots. The DFG can take place only when the signal and pump pulse overlap. The strong chirp present in the pump pulse: (1) causes that only part of the pump spectrum takes part in DFG, (2) maps the signal temporal envelope onto the output spectral envelope, (3) is translated to the chirp of the output pulse. The output chirp compensation allows compressing the long input pulse into a short output pulse. (b,c) Experimental spectral bandwidth expansion.

Our converter is based on the difference frequency generation (DFG) process in a periodically-poled waveguide in a lithium niobate crystal. The pump is generated by a custom setup where 2070 nm wavelength pulses from an frequency shifted erbium femtosecond oscillator are stretched by purpose-fabricated chirped fiber Bragg grating (CFBG) with dispersion of 340 ps/nm, and amplified in a thulium fiber amplifier. The 798 nm single-photon-level input signal interacts in the crystal with the strong 2070 nm chirped broadband pump and is converted to 1300 nm and spectrally broadened. The 1300 nm output can be then compressed using another CFBG with dispersion of 800 ps/nm. The exact output wavelength is decided by the energy conservation in the QFC. The unique ability of our device to simultaneously modify the spectral bandwidth and duration of the photon pulse comes from applying a strongly chirped pump, as shown in Fig. 1a.

We converted single-photon-level coherent light pulses matching parameters of a quantum dot of 798 nm, 5.2 GHz bandwidth and 150 ps duration to a standard telecommunication channel of 1300 nm, 35 GHz (< 100 GHz channel separation), and 25 ps. To match the 35 GHz of telecom bandwidth we needed 34.4 GHz of pump bandwidth, which together with 150 ps of pulse duration yielded 306 ps/nm (4.37 ps/GHz) pump dispersion. The custom CFBG provided 340 ps/nm (4.86 ps/GHz) which in QFC translated to 804 ps/nm (4.53 ps/GHz). Using a compensating CFBG of 800 ps/nm (4.62 ps/GHz) we are able to compress the output pulse below the temporal resolution of our detector (25 ps). The measured internal conversion efficiency was above 80%.

Using our converter we were able to efficiently convert weak coherent light pulses analogous to those from a typical quantum dot to an O-band fibre telecommunication standard. An appropriately modified version could be used on the other end of channel to convert the single-photons to parameters matching a quantum memory, therefore constituting a complete quantum link useful in, e.g., entanglement swapping. Further developments would allow for control of the output envelopes shape, e.g., changing the exponential decay for Gaussian. We demonstrated the capability of QFC to perform complex spectral-temporal shaping: our converter performs frequency conversion, bandwidth shaping and duration control into a single step.

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Importance of passive PT symmetry for quantum operations

Thu – 18

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Decay plays a negative role in quantum information processing. Despite this fact, there are rare cases where decay can be useful for performing quantum operations. For example, cavity decay has been shown to be able to significantly improve the fidelity of a state mapping operation because it acts as a counterpoise to atomic decay. Here, we show the explanation of this phenomenon – a quantum system experiencing two types of damping is able to perform high-fidelity quantum operations, when the whole system is in a passive PT-symmetric regime, because in this regime the periodicity of an evolution of the quantum state is protected [2].

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Towards high-resolution cavity-enhanced two-dimensional infrared spectroscopy

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2DIR spectroscopy is a powerful and well-developed experimental technique, commonly used to study ultrafast molecular dynamics in optically thick liquid-phase and solid-state samples. Advances in generation of high-power optical frequency combs in the mid infrared and in cavity enhancement of ultrafast nonlinear signals provide a way to extend 2DIR measurements to weakly absorbing samples, in particular to low-concentration gas-phase samples [1]. The high sensitivity of these techniques can be combined with the high resolution of multicom comb spectroscopy or Fourier-transform spectroscopy to enable measurements of the shapes of individual resonances.

In this contribution, I will present our plan for the experimental realization of CE-2DIR spectroscopy and present the current status of the project. Our setup is based on a home-made Yb: fiber frequency comb with 200 MHz repetition rate. The laser pulse train will be amplified to <20 W average power, and the pulses will be compressed to ~150 fs duration. We will use several difference frequency generation setups to efficiently generate mid-IR frequency combs and match them to higher order modes of an optical cavity. Based on the one-cavity scheme discussed in Ref. [2], we will use acousto-optic modulators to produce frequency-shifted copies of the original comb and use phase masks to efficiently couple them to different transverse modes of an optical cavity. All the frequency combs will be coupled collinearly to a single standing-wave cavity, which will ensure pump-probe overlap over the whole length.

The first application of the setup will be to solve a longstanding problem in the theory of molecular line shapes—the problem of optical coherence diffusion in the gas phase [3].

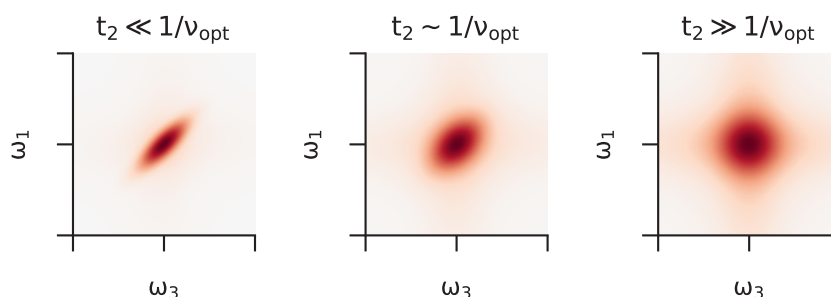


Fig. 1: A cartoon of a 2D gas-phase molecular line shape affected by coherence-damping and velocity-changing collisions. Left: Immediately after pump excitation the anti diagonal gives the speed-dependent pressure width. Middle: Collisions thermalize the velocity distribution of rovibrational coherences, bringing it closer to the Boltzmann distribution. Right: At long delays the velocity distribution is fully thermalized and the profile is fully symmetric.

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Quantum Optics XI

Discrete Time Quantum Walks with Absorption and the Heisenberg Reset

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We explore the effects of stochastic resetting on discrete-time quantum walks (DTQW) on a finite one-dimensional lattice with two absorbing boundaries. These absorbing sites act as detectors and allow us to study the mean time to absorption (MTA) - a quantity central to first-passage problems.

In the classical case, resetting typically increases the MTA when the walk starts symmetrically between the absorbing sites. Surprisingly, in the quantum scenario, we observe the opposite: stochastic resetting can optimize and reduce the MTA. The quantum walk exhibits a dependence on the reset probability, featuring a clear minimum at an optimal value (see Fig. 1).

This behavior is rooted in quantum mechanics. Unlike classical resetting, which only affects position, quantum resetting modifies both the walker's position and its quasi-momentum distribution, a consequence of the uncertainty principle. This leads to reduced interference-based reflection from absorbing boundaries and faster absorption overall.

We provide heuristic estimates of the optimal reset rate and demonstrate agreement with numerical results. Our findings reveal a clear quantum advantage in scenarios where classical walks cannot be optimized and suggest practical applications for speeding up quantum algorithms through controlled resets.

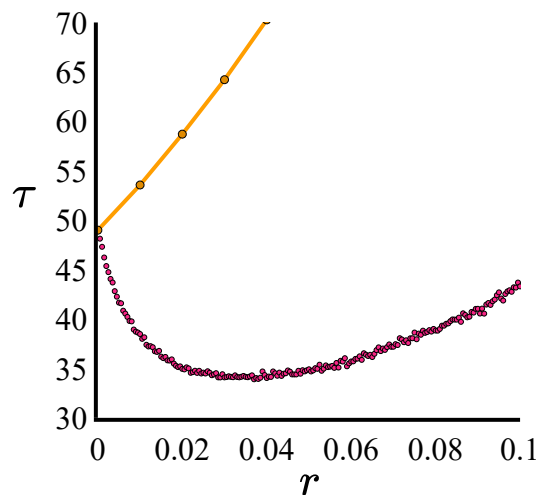


Fig. 1: Mean time to absorption τ as a function of resetting probability r for quantum (pink dots) and classical (orange dots connected by line) walks. This figure demonstrates the fundamental difference in behavior between quantum and classical walks under stochastic resetting, highlighting the regions where quantum advantage emerges. This result was obtained in [1].

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Thu – 21

Ultracold CaF–Yb: interactions, electric-field scattering resonances, and prospects for triatomic molecule formation

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There has been much recent progress in cooling molecules to ultracold temperatures, particularly laser cooling molecules like CaF. There is now interest in controlling collisions of such molecules with ultracold atoms, and using these to form triatomic molecules. Such molecules will have novel levels structures and are expected to have application in studies of quantum information/simulation, fundamental chemical reaction dynamics, and high-precision spectroscopy searches for beyond-standard-model physics.

Here, we focus on the CaF+Yb system. We have calculated the interaction potential of the triatomic complex. It is highly anisotropic, with its global minimum bound by 8000 cm^{-1} in a bent CaF–Yb configuration (Fig. 1a). In scattering, the anisotropy provides a strong coupling between rotational states of CaF, but is not likely to drive strong magnetic Feshbach resonances due to the lack of spins on the Yb. Instead we focus on effects of electric fields, where resonant states can be coupled directly by the interaction anisotropy. We have calculated scattering lengths as a function of electric field up to 20 kV/cm and find a rich spectrum of Feshbach resonances (Fig. 1b), which we locate and characterise numerically. The resonances are fairly sparse and narrow below 5 kV/cm but increase dramatically up to 10 kV/cm and beyond. The widest have widths of several kV/cm but there are also many narrower. They will be suitable both for controlling collisional interactions, and for electro-association to weakly-bound triatomic complexes, analogous to magneto-association.

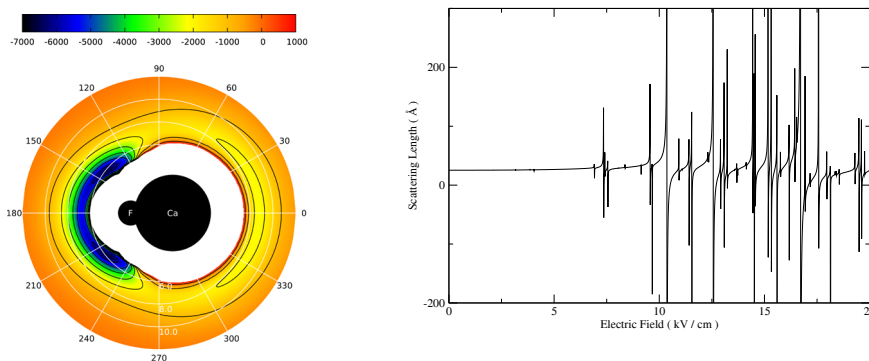


Fig. 1: Left: CaF+Yb interaction potential. Right: Scattering lengths as a function of electric field, showing many Feshbach resonances.

If the weakly-bound molecules can be optically transferred to the triatomic ground state by STIRAP, preliminary calculations suggest these will have high sensitivity to CP-violating physics. This is largely due to the presence of the heavy Yb atom, which enhances relativistic effects; if ^{173}Yb is used, its quadrupole-deformed nucleus will further enhance sensitivity to some of these effects. The bent ground-state molecule also has a novel level structure that can aid in high-precision spectroscopy. In particular, there are closely spaced states of opposite parity, which allow polarisation of the molecule with modest electric fields, expected to be of order only 10 s of V/cm , and facilitate cancellation of systematic errors.

These results pave the way for a new generation of experiments towards control of ultracold atom+molecule mixtures, formation of ultracold triatomic molecules, and searches for physics beyond the standard model. The electro-association method is completely general and does not rely on any spin structure or state, so can be applied to any combination of heteronuclear molecule and atom.

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Quantum advantage in highly polarized spin ensembles

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Quantum-enhanced sensing through spin squeezing has emerged as a powerful technique to surpass classical sensitivity limits in precision measurements [1]. In the present work, we aim to demonstrate the quantum advantage of spin squeezing in highly polarized atomic ensembles within microfabricated isotopically enriched ^{87}Rb cells.

Here we present the development of an optically pumped magnetometer (OPM) capable of detecting spin projection noise at high magnetic fields ($\sim 50\mu\text{T}$). Achieving high atomic polarization to the system benefits from the light narrowing effect, which increases sensitivity by improving the signal-to-noise ratio [2]. We determined the squeezing parameter, quantifying the noise reduction with respect to a coherent spin state, and we explore the potential benefits of combining spin squeezing with squeezed light probing to achieve further noise reduction. We present preliminary simulations results to evaluate the level of spin squeezing that can be achieved in the light narrowing regime, as shown in figure 1.

This work represents a step forward in developing compact and highly sensitive magnetometers, with potential applications in fundamental physics experiments and field-deployable precision sensing technologies.

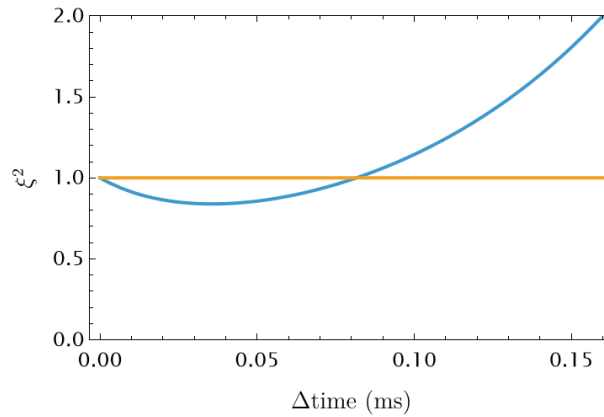


Fig. 1: Degree of squeezing vs time of interaction. In orange, degree of squeezing for a coherent state. In blue, the degree of spin-squeezing expected in our system under the conditions of the cell heated at 180°C , with 10 mW of probe power and 200 GHz detuned from the ^{87}Rb D_1 line.

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⁸⁷Rb Spinor BEC ComagnetometerZ. Sargianni^{*1}, B. Soria Pastor¹, G. Łukasiewicz^{2,3}, W. Zhou^{1,4}, E. Aybar¹, N. Lundblad^{1,5}, A. Sierant¹, M. W. Mitchell^{1,6}¹ICFO - The Institute of Photonic Sciences, Castelldefels (Barcelona), Spain²Marian Smoluchowski Institute of Physics, Jagiellonian University in Kraków, Poland³Doctoral School of Exact and Natural Sciences, Jagiellonian University, Poland⁴IFAE - Institut de Física d'Altes Energies, Barcelona, Spain⁵Bates College, Lewiston, Maine, USA⁶ICREA - Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

Spinor Bose-Einstein Condensates (SBECs) can be used as highly sensitive magnetometers, utilizing the Larmor precession of atomic spins in a magnetic field to achieve precise measurements. The macroscopic nature of the SBECs, where all atoms are degenerate in the same quantum state, but still exhibit rich spin physics, along with their long coherence times, allow for high-sensitivity measurements. Due to quantum degeneracy and exceptionally low inelastic collision rates, a ⁸⁷Rb SBEC can achieve extremely high magnetic sensitivity relative to its volume, with a combination of spatial, temporal, and field resolution that supresses many existing sensing approaches [1]. This enhanced magnetic sensitivity at small length scales enables new opportunities for probing physics beyond the Standard Model, such as searches for short-range spin-dependent forces that may provide insights into dark matter detection and gravitational quantum effects.

In this work, we present one advantage of the ⁸⁷Rb SBEC, which is its ability to function as a comagnetometer, a two-component SBEC, where the $f = 1$ and $f = 2$ hyperfine ground states of ⁸⁷Rb act as co-located magnetometers. Each of them can directly image the Larmor precession of an SBEC using nondestructive Faraday rotation probing with the additional benefit that these hyperfine manifolds have nearly opposite gyromagnetic ratios, leading to counter-rotating precession angles. This setup allows for effective rejection of common-mode noise and enhances sensitivity to any effects that affect the two manifolds in opposite ways, such as interactions that rotate them in the same way [2].

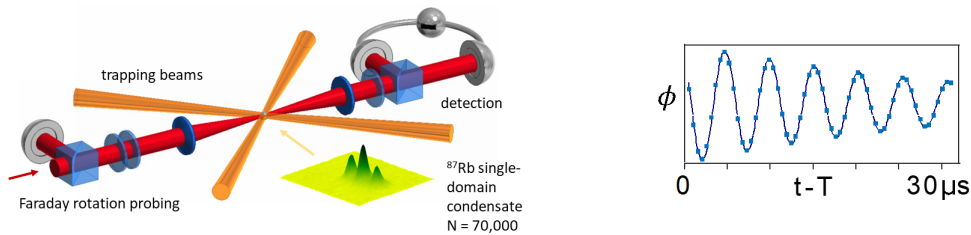


Fig. 1: The SBEC magnetometer is initially prepared and confined within an optical dipole trap (orange beams). The atomic spins are first polarized along the magnetic field and then tipped orthogonally to the field using an RF pulse. A linearly polarized probe beam (red beam) passes through the atomic ensemble, undergoing Faraday rotation by an angle ϕ as the spins precess in the magnetic field. The Faraday rotation angle ϕ is proportional to F_z , where F is the collective spin of the condensate. By measuring ϕ , we determine F_z , which encodes the precession angle—a direct function of the magnetic field strength. (Left) Schematic of the SBEC-based magnetic field sensor. (Right) Readout measurements of the Faraday rotation angle ϕ as a function of time t . Adapted from [3].

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Unitary spectral-temporal mode shaping for applications in photonic quantum information processing

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The accelerating development of quantum network technologies has created an urgent need for quantum information exchange across diverse systems. This critical transfer capability, particularly over vast distances, can be achieved almost exclusively through single photons serving as quantum information carriers.

A two-photon interference is one of the standard methods to exchange quantum information between photons. The interference of quantum states requires the indistinguishability between both states, which is realized by matching the properties of interacting photons. For instance, a quantum dot (QD) source, producing single-photon wavepackets with exponential decay in time and matching spectral mode has a very limited probability of being stored in a quantum memory using an atomic vapor [1]. The overall efficiency could be improved by using a quantum photonic interface (QPI) – a device matching properties of photons by manipulating their spectral and temporal degrees of freedom. Here, we could modify the temporal profile of the QD photons to transform it into a Gaussian mode. Such interfaces can be created using inherently lossless phase-only operations [2], but current approaches require multi-stage transformations, with each stage introducing loss and potential instability.

Here we present a single-stage process for changing an arbitrary spectral-temporal mode pulse into any other arbitrary spectral-temporal mode by using only a single temporal and a single spectral phase. When the temporal phase is changed, the temporal amplitude of the input pulse is not modified, but the spectral amplitude changes. When the spectral phase is applied, the spectral amplitude is intact, while the temporal amplitude changes, see Figure 1a. Performing the transformation requires us to find the specific spectral and temporal phases transforming the input mode pulse into the desired output mode pulse. Using machine learning techniques allows us to put additional constraints on the problem through a customized loss function. We can use the loss function to include experimental limitations, such as resolution and limited analog bandwidths (frequency range).

In Figures 1b and 1c, we present numerical results obtained by the convolutional neural network method for the conversion of a long pulse from a quantum dot with an exponential decay envelope in time into a Gaussian pulse. This is a particularly interesting process for photonic quantum information processing, as a quantum interface allowing Gaussian photons to interfere with single photons from quantum dots will enable the creation of a fast and reliable quantum network.

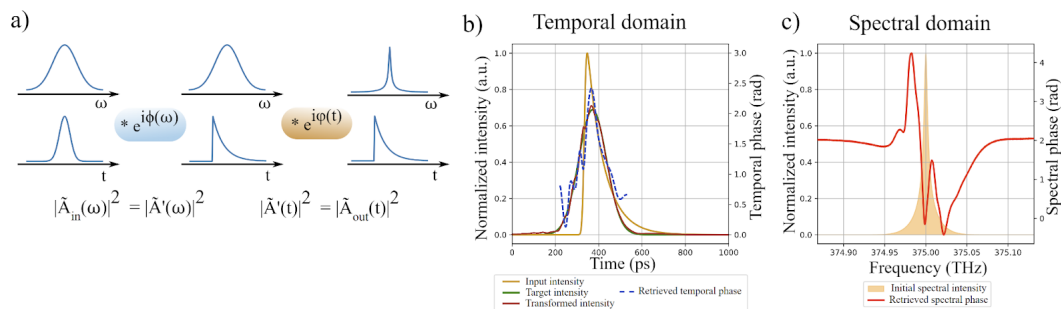


Fig. 1: (a) Schematic of the unitary spectral-temporal mode shaping using only two phase operations. (b-c) Numerical results for the exponential to Gaussian pulse conversion. Please note, that the obtained phases are continuous and slowly changing, indicating the feasibility of implementation these transformation experimentally.

We present an arbitrary spectral-temporal mode transformation by applying a single temporal phase and a single spectral phase. The customizable loss function allows us to fine-tune the parameter search properties to achieve the best possible experimental results. These results will find applications in spectral-temporal mode matching for hybrid quantum networks and quantum information processing in the time-frequency degree of freedom. We also expect potential applications for specific classical high-intensity pulse shaping scenarios.

This research was funded in part by the National Science Centre, Poland, grant number 2022/45/N/ST2/04249.

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Hybrid Sampling Method for BEC Fluctuations

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We demonstrate the advantages of a new hybrid sampling method to solving the problem of ensemble BEC fluctuations for the cases of many interacting bosons in various system geometries: harmonic traps (1D, symmetric and asymmetric 3D) and boxes with periodic boundary conditions.

We combine the field's workhorse – the classical fields approximation (CF) – with our new method – Fock state sampling (FSS) – and we obtain an extremely robust method without the problems of CF, i.e. without the "cutoff problem" (UV divergency). The method maintains its general applicability to many different systems and allows us to study a wide range of properties, not only BEC fluctuations.

FSS was first demonstrated in [1] where we compare experimental data (first experimental measurement of BEC fluctuations) with our theoretical predictions. Since then, FSS was applied for many different systems and geometries [2], providing us with access to both canonical and microcanonical ensembles for the study of BEC statistics. Our new hybrid sampling method retains this ability to study different ensembles and geometries.

In this presentation we focus on highlighting our new results for a repulsively interacting Bose gas in an asymmetrical 3D harmonic trap and compare them with the original experiment [1].

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Towards violation of Bell inequalities by position measurements for Dirac particles

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The natural extension of hidden variables to the realm of relativistic physics would be a hypothetical theory in which trajectories (i) exists, consistent with a local hidden variable (LHV) model, and (ii) remains subluminally. Interestingly, the simplest inequality arising from these assumptions in the bipartite case is satisfied by the Dirac equation [1]. This suggests that its dynamics could, in principle, be simulated by LHV theories with causal (i.e., subluminal) trajectories. Motivated by this, we aim to explicitly refute LHV theories for the Dirac equation, drawing an analogy to similar results established for the Schrödinger equation [2]. In this work, we present evidence supporting such a refutation and outline steps towards its quantitative assessment [1].

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Thu – 27

Diamond magnetometry of type-II superconductors using nitrogen-vacancy centers in nanodiamonds

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One of the most promising applications of nitrogen-vacancy (NV) centers is studying nanoscale magnetic phenomena in superconducting materials. In particular, NV centers in nanodiamonds provide a microwave-free, non-invasive platform for probing superconductors through near-zero-field cross-relaxation magnetometry. In this work, we use NV centers to investigate the magnetic properties of thin-layer of various type-II superconductors. For this study, we deposited nanodiamonds on thin films of superconductors to measure key parameters, including the transition temperature and lower critical field. The strong B-field dependence of the NV photoluminescence allows us to investigate the Meissner effect and other key parameters. Here, we present an all-optical, microwave-free method that utilizes the NV center in diamond as a non-invasive quantum sensor and shed some light onto the possibilities for practical applications of unconventional superconductors.

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Poster sessions

Thursday

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Measurement of quantum negativity via moment operators for two-qubits and qubit-qutrit cases

Thu – 28

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Quantum entanglement detection remains a fundamental challenge in quantum computing, with traditional approaches limited by exponential scaling. Quantum state tomography requires $O(4^n)$ measurements for complete state reconstruction, making it impractical for larger systems. Linear entanglement witnesses demand prior knowledge of target states, while existing methods face inherent trade-offs between sensitivity and selectivity.

We present a framework that efficiently measures quantum negativity through the statistical moments of partially transposed density matrices without requiring full state tomography. Our approach introduces moment operators W_n that directly access entanglement information via quantum circuits implementing controlled-SWAP (CSWAP) gate sequences.

The theoretical foundation exploits Newton-Girard identities connecting statistical moments to eigenvalue extraction. Since the direct moment operators are non-Hermitian, we implement Hermitian operators using CSWAP gate decompositions on quantum hardware.

Our methodology extends to qubit-qutrit systems by mapping the 6-dimensional Hilbert space to an 8-dimension three-qubit representation using Bell state encodings. Six moments determine all eigenvalues of the 6×6 partial transpose matrix, enabling entanglement quantification in mixed-dimensional systems.

Simulation validation demonstrates good agreement between theoretical predictions and circuit implementations for paradigmatic states, including Bell states (maximally entangled), product states (separable), and mixed separable states. Circuit depth scales linearly with moment order, requiring only single ancilla measurements compared to exponentially scaling tomographic procedures.

This approach offers significant advantages: polynomial resource scaling versus exponential tomography, implementation compatibility with current quantum hardware, no requirement for prior state knowledge, and direct entanglement quantification without intermediate density matrix reconstruction. The framework opens pathways for efficient entanglement detection in multipartite systems and provides practical solutions for near-term quantum device characterization.

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Thu – 29

The infrastructure of a Polish quantum computer

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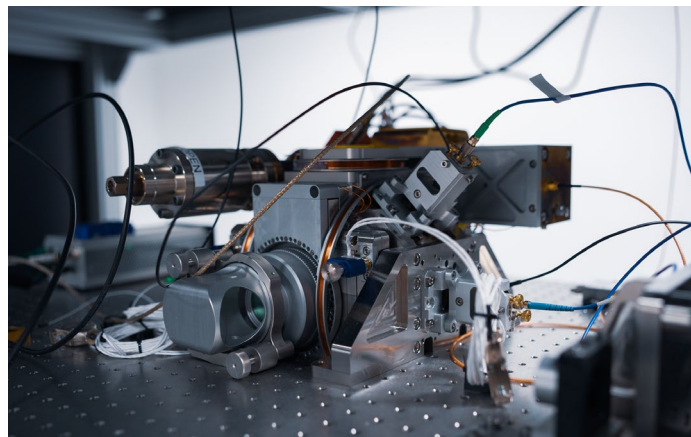
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Trapped ion quantum computers represent one of the most promising platforms for realizing scalable quantum computing. This technology is still in a very early stage of development, but the perspective of utilizing the computational speedup for many demanding computational tasks attracted attention of many scientists, business and governments. The physics behind quantum computing is largely understood, but the technological challenges of constructing an actual quantum computer are formidable. These devices have already left research laboratories, but they are still closer to advanced prototypes than to machines that could be employed by the industry. This is caused, on one hand, by the issue of scaling the qubit number and reducing the error rate, and, on the other hand, by not fully matured technologies standing behind the operation of an ion based quantum computer, like frequency stabilized lasers.

This poster presents an overview of the design, implementation, and challenges associated with constructing an infrastructure of a quantum computer based on laser-cooled $^{40}\text{Ca}^+$ ions. The construction is largely based on technical solutions developed in Poland, especially regarding the control electronics and the software. The dual-use aspect of the infrastructure is reflected in the ability to provide a secure access for multiple users, both via standard internet connections and by a dedicated fiber-optic connection with a remote laboratory.



Poster sessions

Thursday

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Progress Towards a Nuclear Spin-Based Optically Pumped Magnetometer Using Mercury Vapor

Thu – 30

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Optically pumped magnetometers (OPMs) have become indispensable tools in both fundamental research and emerging technologies, with ongoing efforts focused on enhancing sensitivity and miniaturizing active sensing volumes. In particular, OPM technology has seen limited miniaturization beyond sensing volumes of $\approx 1 \text{ mm}^3$. This limitation is primarily due to the worse collisional decoherence at smaller vapor cell volumes affecting the electron spins in the alkali and metastable ^4He vapors commonly used. Nuclear spin-based OPMs offer a promising path toward sensitive sub- mm^3 magnetometry by leveraging the long coherence times associated with nuclear spin ensembles. In particular, mercury (Hg) is an appealing candidate due to its odd isotopes, ^{199}Hg ($I = 1/2$) and ^{201}Hg ($I = 3/2$), which possess nonzero nuclear spin in the ground state and can be optically probed and pumped via the $254 \text{ nm } ^1S_0 \rightarrow ^3P_1$ transition. This transition exhibits high on-resonant optical depth, enabled by mercury's high vapor pressure at room temperature.

To date, Hg-based OPMs remain underexplored, with most research efforts focused on application toward permanent electric dipole moment searches [1,2]. In this work, we present recent progress toward the development of a mercury-based OPM apparatus, including initial characterization of Hg vapor cells with varying anti-relaxation coatings, buffer gas pressures, cell geometries, and Hg vapor pressures using a 254 nm laser. Our goals include exploring the fundamental sensitivity limits of mercury optically pumped magnetometry by leveraging the long coherence times expected in Hg vapor even at high atomic densities. We also investigate miniaturization strategies for magnetic microscopy applications that are compatible with the 254 nm UV light required to optically address mercury atoms. Finally, we aim to explore using the optically addressable nuclear spins in mercury vapor as a platform for quantum-enhanced metrology.

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Size-Independent Nonstabilizerness in Metrological States

Nonstabilizerness, also known as “magic”, is a resource which quantifies the amount of beyond-Clifford operations needed to prepare a quantum state. While entanglement is a well known resource for quantum computations, by itself is not sufficient to guarantee quantum advantage, achieved when the state of a quantum device is not tractable by classical computers. Nonstabilizerness has been established as another resource essential for achieving the quantum advantage. In this work we study the stabilizer Rényi entropy (SRE), a well-known measure of nonstabilizerness, from a quantum metrology perspective; we relate SRE generation through one-axis twisting dynamics with quantum Fisher information and relevant many-body Bell correlators. Contrary to typical phenomenology of SRE in many-body systems, we find states for which the SRE quickly converges with the system size. For instance, particular superpositions of n spin-coherent states show fixed values of SRE which, after certain system sizes, only depend on n . We also study the relation between SRE and many-body Bell correlations for eigenstates of the Lipkin-Meshkov-Glick model. Our results pave the way for generally defining states which are useful for metrology but can be classically simulated with high efficiency.

This work was funded by the National Science Centre, Poland, project 2021/03/Y/ST2/00186 within the QuantERA II Programme (DYNAMITE) that has received funding from the European Union Horizon 2020 research and innovation programme under Grant agreement No 101017733.



Double-driving in a nonlinear ion–nano-wire hybrid system

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Laser-cooled ions confined in strong electromagnetic fields are a well-established tool for atomic and molecular physics or quantum optics [1,2]. In parallel, nano- and micromechanicals systems have established themselves as very precise tools [3], notably acting as a cross-over between the microscopic and macroscopic worlds [4,5]. The perspective of a hybrid system capable to harvest new insights [6] motivates the development of an ion–nano-wire hybrid system that would be capable to achieve the control and probing of both system with the other [7]. Recently, we have reported the experimental demonstration of the coupling of $^{40}\text{Ca}^+$ ions with an oscillating charged Ag_2Ga nano-wire [8,9] (Fig. 1). Considering a single-point charge approximation and a monochromatic drive frequency of the nano-wire, an analytical model for the coupling between the $^{40}\text{Ca}^+$ ion and the nano-wire has been derived (Eq. 1 and 2) and has proved to be in good accordance with the first experimental results [8,9]. Further experiments will allow to explore capabilities such as amplitude and phase control of the trapped ion or the characterisation of the interaction. Also this system may provide a good platform for the exploration of the physics of Duffing oscillators, notably through a double-drive experiment (Eq. 3). This experimental demonstration is a first step towards the creation of more sophisticated ion–nano-wire couplings in the quantum regime such as inducing coherent states of motion or the probing and control of the states of an ion and a nano-wire [7].

$$F_{nw} = A_{nw} \cos(\omega_{nw}t + \varphi_{nw}) \quad (1)$$

$$A_{nw} = -\frac{q_{ion}q_{nw}}{4\pi\epsilon_0} \frac{1}{d_{nw}^3} \left(1 - 3\frac{z_{nw}^2}{d_{nw}^2}\right) \times 184.42 \cdot 10^{-9} V_{piezo} \quad (2)$$

$$\ddot{x} + 2\mu\dot{x} + \gamma x^3 + \omega_0^2 x + \alpha x^3 = k_{tkl} \cos(\omega_{tkl}t + \varphi_{tkl}) + k_{nw} \cos(\omega_{nw}t + \varphi_{nw}) \quad (3)$$

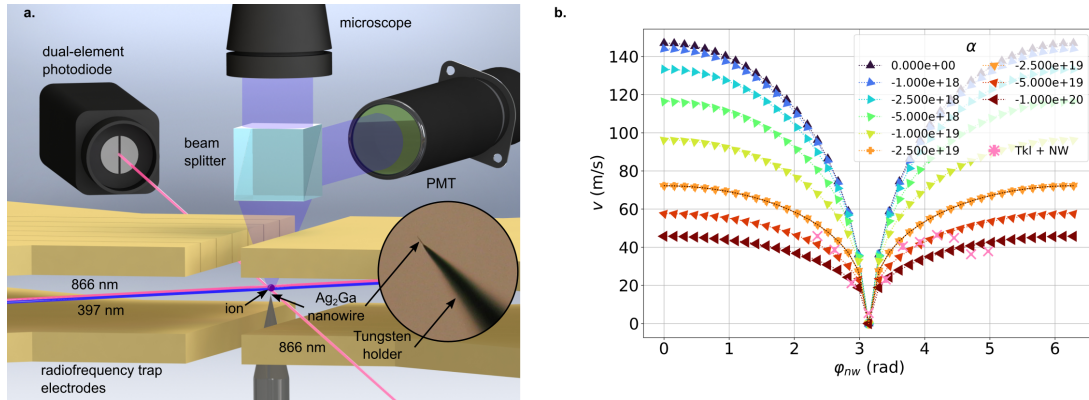


Fig. 1: The ion–nano-wire hybrid system. **a.** Schematic of the experimental setup. The nano-wire is positioned close to the trapped ions in a miniaturised trap made of four wafers separated by 400 μm . **b.** Oscillator maximum velocity vs. relative phase between the two driving forces of same amplitude ($\varphi_{tkl} = 0$). Coloured triangles are the numerical solutions of the model for different anharmonicity constants α . Pink crosses are experimental results.

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Ultracold molecules a testbed for physics beyond the Standard Model

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The Standard Model of Particle Physics (SM) provides a good description of matter, radiation, and their interactions. Unfortunately, there are still open questions in science where SM cannot accurately describe observed phenomena such as the matter-antimatter imbalance. A promising approach to uncovering physics beyond the SM is to identify novel sources of combined charge and parity ($\mathcal{CP}$) violation. The presence of $\mathcal{P}$, $\mathcal{T}$ -odd forces and permanent electric dipole moments of elementary particles may induce a non-zero molecular dipole moment of the entire system, leading to subtle shifts in the molecule's energy structure [1]. In this work, we propose a new class of molecular systems – ultracold high-spin Σ -state polar molecules, such as YbCr and RaCr – as sensitive platforms to study $\mathcal{CP}$ violation in the hadronic and leptonic sectors. We theoretically modeled the formation of these molecules from ultracold high-spin spherically symmetric atoms with closed-shell atoms. We found that these systems can be easily polarized due to the presence of Ω doubling and used for precision measurements. We analyzed their molecular properties using relativistic *ab initio* quantum chemical methods. We carefully investigated enhancement factors describing the sensitivity of molecules to the $\mathcal{CP}$ -odd nuclear magnetic quadrupole moment, electron electric dipole moment and electron-nucleon scalar-pseudoscalar interactions [2]. Possibility of the formation of YbCr [3] or RaCr in ultracold temperatures makes them great for high-precision experiments due to enhanced sensitivity of an experiment. In this manner, we want to pave the way for a new class of very promising systems for the next generation of SM-physics searches at the low-energy frontier.

Acknowledgments

We gratefully acknowledge the European Union (ERC, 101042989 – QuantMol), the National Science Centre, Poland, within Preludium (Grant No. 2024/53/N/ST2/03814) and the PL-Grid Infrastructure (Grant No. PLG/2023/016115)

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Demonstration of Fourier-domain Quantum Optical Coherence Tomography for a fast tomographic quantum imaging

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Using spectrally correlated photon pairs instead of classical laser light and coincidence detection instead of light intensity detection, Quantum Optical Coherence Tomography (Q-OCT) outperforms classical OCT in several experimental terms. It provides twice better axial resolution with the same spectral bandwidth and it is immune to even-order chromatic dispersion, including Group Velocity Dispersion responsible for the bulk of axial resolution degradation in the OCT images. Q-OCT has been performed in the time domain configuration, where one line of the two-dimensional image is acquired by axially translating the mirror in the interferometer's reference arm and measuring the coincidence rate of photons arriving at two single-photon-sensitive detectors. Although successful at producing resolution-doubled and dispersion-cancelled images, it is still relatively slow and cannot compete with its classical counterpart. Here, we experimentally demonstrate Q-OCT in a novel Fourier-domain configuration, theoretically proposed in 2020, where the reference mirror is fixed and the joint spectra are acquired. We show that such a configuration allows for faster image acquisition than its time-domain configuration, providing a step forward towards a practical and competitive solution in the OCT arena. The limitations of the novel approach are discussed, contrasted with the limitations of both the time-domain approach and the traditional OCT.

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Addressing Challenges in Near-Infrared Squeezed Light Generation: Absorption Effects and Phase Stabilization

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A light squeezer is an optical system that exploits Heisenberg's uncertainty principle, reducing quantum noise in one quadrature of the electromagnetic field at the expense of increased noise in the conjugate quadrature. Common implementations of light squeezers include optical parametric oscillators (OPOs), where a nonlinear crystal inside a resonator mixes two beams (pump and signal), converting energy from the pump wavelength to the wavelength of interest in a process known as parametric down-conversion. Typically, the higher the pump power, the greater the squeezing achieved, with squeeze factors reaching values between 13 and 15 dB [1, 2]. However, when the wavelength of interest lies close near-infrared spectrum, the pump (whose wavelength lies near blue spectrum) induces absorption of the signal beam by the crystal, converting optical power into heat in a process known as Blue Light Induced InfraRed Absorption (BLIIRA)[3].

Here we present an initial design of our new light-squeezer at the Rubidium D1 transition-resonant wavelength, based on the design proposed by [4], with a primary focus on the OPO design. The detrimental effects of BLIIRA will be explained, along with the choice of a proper crystal to mitigate it. Additionally, a dual coherent locking technique to lock the phases of the pump and a local oscillator -similar to that found in [5]- will also be described.

The project that led to these results received the support of a fellowship from Fundació Ramón Areces.

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Mid-infrared scanning microscopy with undetected photons

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Method of quantum imaging with undetected photons (QIUP) [1] has been decisive in extending the accessible spectral range for probing and imaging of biological samples. The classical MIR imaging techniques use mid-infrared sources and detectors which are costly, noisy and with a poor performance in respect to the visible and NIR counterparts. On the other hand, microscopic imaging with QIUP scheme is a cost effective and powerful method for hyperspectral imaging which could help to reliably distinguish between different cells and tissues morphologies. Additionally, imaging at the single photon level prevents photo- and thermal damage of the bio-samples.

We will present our quantum interferometric set-up, exploiting induce coherence phenomena [2], while employing nonlinear crystal as a medium for generation of entangled, highly nondegenerate photon pair (signal and idler) via SPDC (spontaneous parametric down-conversion) process. The interferometer, in Michelson configuration, is formed in a double pass of the pump through 30 mm long ppKTP crystal [3]. The bio-sample to be imaged is put on the path of the idler photons ($\lambda_i=2400$ nm), while the information on the absorption and the phase of the idler upon the interaction with the object is obtained solely from the detected signal photons ($\lambda_s=487$ nm). Furthermore, with the particular design of the experimental scheme and the point-wise detection, we have managed to obtain special resolution of 16.7 ± 3 μm , well below predicted values for the standard QIUPs relying on the spatial correlations.

We will demonstrate the capabilities of our system for acquiring the images of biological samples. This study provides a foundation for future improvements in the design and optimization of the scanning QIUP schemes.

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Optical pumping and re-pumping with frequency modulated light for high accuracy magnetometry using Cs vapor cell

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We demonstrate a novel approach for optical pumping (OP) to increase sensitivity of free alignment precession (FAP) based magnetometer. The sensing element is cesium (Cs) vapor cell with paraffin antirelaxation coating. The Pump-Repump with Frequency Modulation (PRFM) technique employs a single laser source to achieve simultaneous optical pumping and repumping of Cs atoms within a vapor cell. Unlike conventional methods that rely on amplitude modulation (AM), PRFM leverages frequency modulation (FM) of the laser's wavelength to address multiple atomic transitions concurrently.

One measurement cycle of a FAP magnetometer consists of a pump and probe intervals as presented in Fig. 1. Pump light intensity is modulated at double of Larmor frequency. The pump should produce maximal alignment in shortest interval. Length of the probe interval is limited by relaxation rate and noise level. Cramer-Rao Lower Bound Limit (CRLB)[1] is used as criteria for optimization. If pump is too intensive or too long the amplitude of the FAP will be reduced.

Specifically, the frequency-modulated laser output is tailored such that distinct portions of its spectral bandwidth are resonant with different transitions within the Cs atom's ground-state hyperfine structure. A component of the laser spectrum performs OP of atoms on the $F_g = 4 \rightarrow F_e = 3$ transition (D_1 line), thereby producing the spin alignment used for magnetic field sensing. Simultaneously, another spectral component performs repumping of atoms from the $F_g = 3$ ground state back into the $F_g = 4$ ground state over excited states. This continuous repumping action mitigates population accumulation in the $F_g = 3$ state, which would otherwise reduce the FAP signal amplitude. According to our preliminary theoretical and experimental data, the pump intensity nor length of the pump interval do not reduce maximal alignment.

By performing optical pumping and repumping concurrently with a single, frequency-modulated light source, PRFM minimizes dead time and maximizes the utilization of available atoms. This results in an enhanced FAP signal, improved magnetometer sensitivity, and the potential for increased sampling rates. Furthermore, the simultaneous excitation of both ground states facilitates the potential for simultaneous readout of Larmor frequencies from both $F_g = 3$ and $F_g = 4$ states, enabling more comprehensive characterization of the applied magnetic field.

This technique has potential applications in diverse fields including Earth's field anomaly detection, biomagnetism, exotic physics searches within the Global Network of Optical Magnetometers to search for Exotic physics (GNOME)[2], measurement of neutron electrical dipole moment (nEDM)[3], etc.

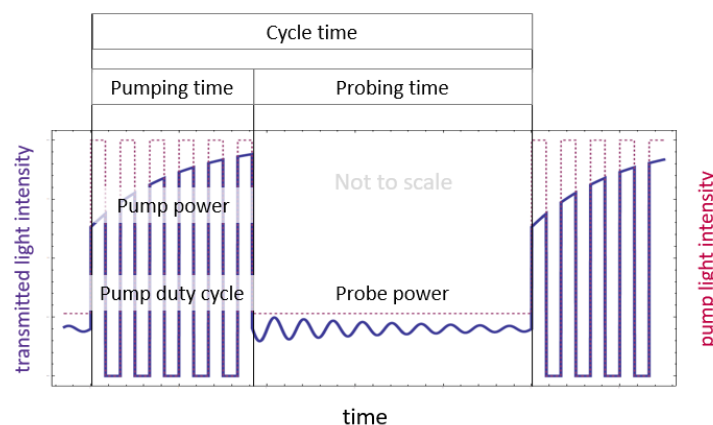


Fig. 1: Graphical presentation of FAP magnetometer measurement cycle.

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Optimal measurement induced squeezing for CV cluster states

Thu – 38

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In recent years, there has been rapid development in continuous variable quantum computing (CVQC). Cluster states, which are necessary for CVQC, are commonly created in laboratories [1]. On the way to quantum supremacy, Gaussian operations should be implemented as efficiently as possible because cluster states suffer from losses. We find the optimal method for squeezing in the simplest cluster state, the teleportation scheme. The teleportation scheme in continuous variables can be adapted to teleport and squeeze the input state. This can be done by changing the measurement angles of homodyne detectors [2]. A new approach to measurement-induced squeezing has been introduced [3]. The static beam splitters are replaced with variable ones. This improves squeezing to noise ratio. We compare these two methods, [2] and [3], using the fidelity and properties of the Wigner function.

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Reconstruction of Quantum Gates using Quantum Process Tomography

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Quantum gate reconstruction plays a crucial role in quantum computing by enabling the verification and characterization of quantum operations. Quantum Process Tomography (QPT) is a powerful technique that is used to fully reconstruct the process matrix of a quantum gate, providing a comprehensive understanding of its behavior. By utilizing QPT, one can identify imperfections in quantum gates, making it an essential tool for the development of reliable quantum computing systems.

In this study, we present our experimental investigations on the reconstruction of quantum gates using the QPT technique in the qutrit system. The core of our experimental setup is a room-temperature ^{87}Rb atomic vapor cell, which contains two hyperfine ground states with $F = 1$ and $F = 2$ (F is the total angular momentum). To achieve a qutrit system, the $F = 2$ state is depleted using a laser beam. To perform the QPT, a set of initial states corresponding to the Gell-Mann matrices is chosen. By comparing initial states with their evolved counterparts, we gain insight into the quantum process. For more insightful characterization of the measured process, we reconstructed the minimal set of Kraus maps that describe measured process. We demonstrate the reconstruction of some fundamental quantum gates, showcasing the high precision of the gate reconstruction using the QPT technique [1,2,3].

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Propagation of Optical Vector Vortices in an Atomic System with Closed-Loop Tripod Configuration

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We investigate the propagation of an optical vector vortex beam in an atomic medium featuring four-level tripod transitions, where ground-state coherence is mediated by a transverse magnetic field [1]. The vector beam consists of left- and right-circularly polarized components, each carrying an optical vortex with opposite orbital angular momentum (OAM). We study the linear response of the medium to the vector beam in order to determine the evolution of the beam's intensity and polarization profile.

We find that the beam structure undergoes significant transformations as it propagates: the transverse intensity evolves from a ring-shaped profile to a petal-like structure, while the polarization transitions between left-circular, linear, and right-circular polarizations [2].

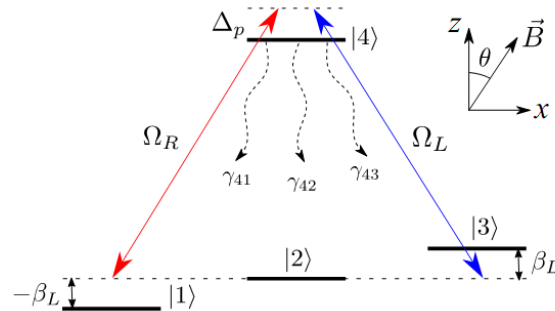


Fig. 1: Schematic diagram of a four-level closed atomic system.

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Non-Hermitian Dynamics of Atomic Systems: The Spectral Role of Quantum Jumps

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Non-Hermitian quantum physics has recently garnered significant interest due to its ability to describe energy dissipation in open quantum systems and to predict exotic phenomena such as exceptional points (EPs). In this context, non-Hermitian dynamics is often modeled using non-Hermitian Hamiltonians (NHHs). While these have been successfully applied in various platforms—particularly in photonic systems [1–3]—their use is now extending to a wider range of systems, including thermal atomic ensembles [4]. However, for some systems, an accurate description of the dynamics often requires a more complete treatment beyond NHHs [5–7].

We investigate this discrepancy using a model of an open atomic system with two hyperfine states ($F = 1$ and $F' = 0$), analyzed using the formalism of effective operators [8]. By comparing the eigenvalue spectra obtained from both an NHH and a Liouvillian superoperator, we analyze the emergence and properties of Hamiltonian and Liouvillian exceptional points, as well as diabolical points.

Our results show that, for atomic systems, relying solely on NHHs can be insufficient for accurately capturing the system's spectral features. While NHHs can provide correct predictions in specific scenarios, a full description generally requires the Liouvillian superoperator, which governs the Lindblad master equation and explicitly incorporates quantum jump terms. We demonstrate that the inclusion of quantum jumps via the Liouvillian formalism can fundamentally alter the spectral properties of the system. Specifically, we present examples where the existence, location in parameter space, or the order of spectral degeneracies differ significantly between the two approaches, underscoring situations where the NHH description breaks down.

Furthermore, by leveraging the hybrid-Liouvillian formalism [9], we illustrate how quantum jumps influence the spectral features predicted by the NHH, ultimately shaping the full spectrum as governed by the Liouvillian.

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Dual-type dual-element atom arrays for quantum information processing

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Optical tweezer arrays of individually trapped atoms have emerged as a powerful platform for quantum computation and simulation. Nonetheless, several key challenges remain, including limited experimental repetition rates, scalable local addressability, and fast, non-destructive, and selective readout. To overcome these limitations, we are developing a novel dual-type dual-species Yb–Rb atom array architecture with the long-term goal of enabling large-scale, fault-tolerant quantum computation and simulation.

In our approach, single Yb atoms—known for their long nuclear spin coherence times—serve as data qubits, while Rb atomic ensembles—with their enhanced collective optical response—function as ancilla. This combination enables reconfigurable local operations, rapid and non-destructive readout of data qubits, and novel schemes for establishing optical quantum links. Detailed numerical simulations suggest that our protocols can achieve high fidelities under realistic experimental conditions, supporting individually addressable single- and multi-qubit operations with fidelities of 99.5% and 99.9%, respectively, as well as fast single- and multi-qubit state readout with fidelities exceeding 99% within tens of microseconds. These capabilities open new pathways toward scalable, fault-tolerant quantum computation, enabling repetitive error syndrome detection and efficient generation of long-range entangled many-body states, thereby expanding the quantum information toolbox beyond existing platforms [1-2].

As part of this effort, we are currently performing spectroscopic measurements of Yb–Rb Rydberg pair interactions, which will serve to benchmark theoretical models of Rydberg states in multi-valence-electron atoms and advance the state of the art in tweezer-array-based quantum processors.

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Vibrationally coupled Rydberg atom-ion molecules**Ilango Maran^{*1}, Liam J. Bond^{2,3}, Jeremy T. Young³, Arghavan Safavi-Naini^{2,3}, Rene Gerritsma^{1,2}**¹Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam, 1098 XH Amsterdam, Netherlands²QuSoft, Science Park 123, 1098 XG Amsterdam, the Netherlands³Institute for Theoretical Physics, Institute of Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, the Netherlands

Recently, a new type of a long range molecule consisting of an ion and a Rydberg atom popularly known as Rydberg atom-ion molecules (RAIMs) has been theoretically proposed [1, 2] and experimentally observed in an ultracold cloud of ^{87}Rb atoms [3]. We use a hybrid atom-ion system to create a linear crystal of ions in a Paul trap with RAIMs attached to its either end to generate ion-mediated Rydberg-Rydberg interactions. We propose a scheme to utilise the common motional modes of a crystal of trapped ions to enhance (facilitation) or suppress (blockade) the probability of forming two RAIMs at the ends of the chain, replacing the typical blockade radius set by the dipole-dipole interaction by the length of the ion crystal. We use detailed Floquet analysis to demonstrate the feasibility of our scheme in the presence of the time dependent rf potential of the Paul trap and identify parameter regimes where the RAIM survives, using an approach based on Landau-Zener-Stückleberg interferometry which studies the effect of an oscillating field on Landau-Zener (LZ) processes [4], aided by scaling arguments. Lastly, we outline future plans on how these RAIMs could potentially be detected in our hybrid atom-ion experiment [5] without the application of an ion microscope.

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Measurement compatibility in multiparameter quantum interferometry

Thu – 44

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It is well-known that the Holevo Cramér-Rao bound (HCRB) represents the ultimate precision limit in the multiparameter setting [1]. However, in general, the fact that it can be fully attained with collective measurements on a large number of copies of the probe state remains purely theoretical [2]. Thus, the realization of this theoretical limit with experimentally implementable metrological schemes requires careful consideration of certain limitations—namely, the challenges of implementing collective measurements, the fragility of the estimation process to losses, and the availability of a limited number of copies of the probe state.

Towards this goal, we use a figure of merit quantifying the attainability of the HCRB with a separable measurement known as measurement compatibility. We evaluate this measure by considering quantum interferometry for an important class of probe states known as the generalized Holland-Burnett (gHB) states [3] and for double homodyne measurement, standard benchmarks for these applications. We focus on the joint estimation of phase and loss, as well as the joint estimation of phase and phase diffusion.

In our examples, we numerically explore the conditions under which minimal measurement compatibility is achieved, both by varying the parameter weights at a fixed values of losses and by varying the losses with equal weights for the parameters (see Fig. 1). We also contrast the measurement compatibility with the fundamental compatibility [4] that is intrinsic to the problem, and identify the extra incompatibility arising due to the choice of our measurement.

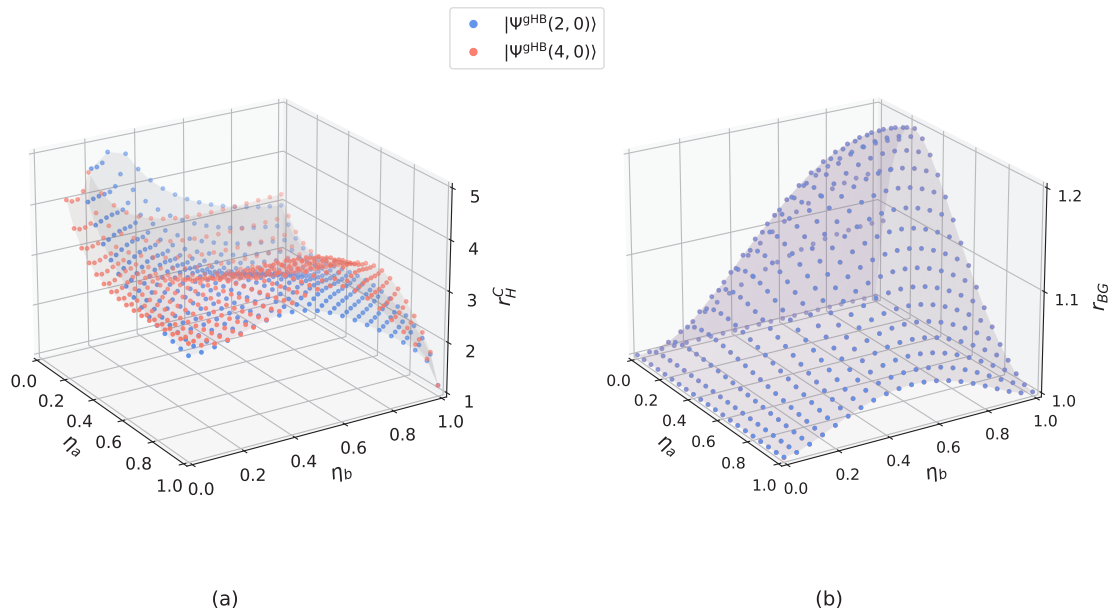


Fig. 1: Joint-estimation of phase and losses: Three-dimensional plots of measurement compatibility r_H^C (panel (a)) and fundamental compatibility r_{BG} (panel (b)) seen as a function of the losses, η_a and η_b , in each arm with equal weights i.e., at $y = 0.5$. The probe state considered here is the gHB state $|\Psi_{gHB}(0, N)\rangle$ with $N = 2$ (blue dots) and $N = 4$ (red dots) which create smooth surfaces. Note that the points closer to low values of losses exhibit high measurement and fundamental compatibilities. Also, the fundamental compatibility does not vary with respect to the chosen values of N for almost all pairs of values of losses.

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Pauli crystall superradiance

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Pauli crystals are unique geometric structures of non-interacting fermions, resembling crystals, that emerge solely from Fermi statistics and confinement [1]. Unlike genuine quantum crystals that arise from interparticle interactions, Pauli crystals do not break translation symmetry but nonetheless exhibit nontrivial many-body correlations. In this work [2], we explore Pauli crystal formation in a cavity-fermion setup. We analytically show that when coupled to a cavity, degeneracy in Pauli crystals can trigger zero-threshold transitions to superradiance. This superradiance is accompanied by the emergence of a genuine quantum crystalline state, wherein the atomic density is periodically modulated. We substantiate our findings using state-of-the-art numerical simulations [3]. The combined interplay between statistics, confinement geometry and interactions mediated by light thus facilitates a novel pathway to quantum crystallization.

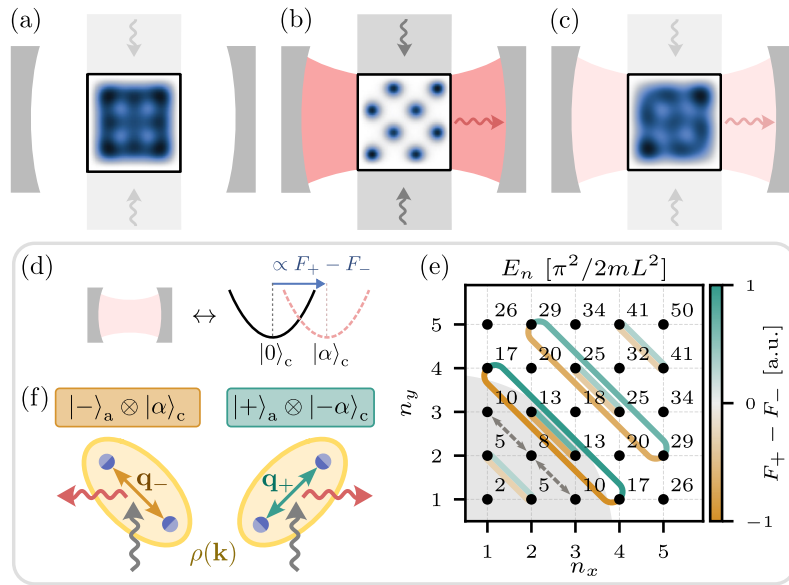


Fig. 1: (a-c) Pauli crystals in a $2\lambda \times 2\lambda$ square box in an optical cavity and driven by laser pumps (grey arrows). (a) For $N = 8$ fermions and at weak pump strength, the unique Pauli crystal ground state remains unchanged and the cavity is empty. (b) For $N = 8$ fermions and beyond a critical pump strength, the Pauli crystal self-organizes into a checkerboard pattern, while triggering superradiant scattering of photons into the cavity (red arrows). (c) With $N = 7$ fermions, the Pauli crystal has degenerate ground states coupled to cavity. The system chooses a configuration maximizing the coherent cavity field already at vanishing pump field. (d) Cavity field as a net displaced harmonic oscillator by the atomic order. (e) Synthetic momentum lattice for a single-particle in a square box, with each eigenmode denoted by its energy. Highlighted pairs of degenerate eigenmodes have cavity mediated coupling $F_+ - F_- = \pm W_{na,nb}^2$. Coupling sign reflects the two $\mathbb{Z}_2$ cavity states associated to $\mathbf{q}_{\pm}$ (colored links). As the spinless fermions fill the eigenmodes, the system exhibits soft transitions if the most energetic fermion occupies an (anti-)symmetric superposition of one of these eigenmode pairs. Otherwise, the system exhibits usual Dicke superradiance between eigenmodes with different energies (dashed arrows). (f) (Anti-)symmetric superposition of Pauli crystals correspond to an elongated Fermi sea along directions of $\mathbf{q}_{\pm}$ which scatters light in the form of a coherent state $|\pm\alpha\rangle$. Figure taken from [2].

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Cesium Microcell Optical Reference at 459 nm With a Frequency Stability in the Low 10^{-13} Range at 1 s

Thu – 46

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Microfabricated (MEMS) alkali vapor cells are at the core of high precision integrated atomic quantum sensors and devices [1], such as microwave and optical clocks, or magnetometers. The first chip-scale atomic device was a microwave atomic clock based on coherent population trapping [2]. It has offered in its industrial and commercialized version an ultra-low size-power-instability budget, impacting a plethora of industrial and scientific applications. Nevertheless, the short-term stability of these clocks is usually limited at about 10^{-10} at 1 s.

Hot vapor MEMS-based optical frequency standards constitute a new generation of miniaturized clocks, with enhanced stability. These references keep the benefit of using wafer-scalable and mass-producible vapor cells while preventing ultra-high vacuum technologies and laser cooling. Among the transitions explored, the $6S_{1/2} - 7P_{1/2}$ transition at 459 nm of Cs atoms was used to demonstrate an optical reference with a stability of 2.1×10^{-13} at 1 s and averaging down to a few 10^{-14} [3]. However, this reference was based on a 5 cm-long glass-blown cell and an electro-optic modulator, not compliant with the advent of a fully-miniaturized and low-power optical clock.

In a previous work [4], we have characterized the sub-Doppler resonances detected in a microfabricated cell by probing, with saturated absorption spectroscopy (SAS), the Cs atom $6S_{1/2} - 7P_{1/2}$ transition at 459 nm. The impact of the laser intensity and cell temperature on the sub-Doppler resonance was experimentally investigated. Optimal values were identified for the development of a microcell-stabilized frequency reference at 459 nm.

In this work, we describe the implementation and short-term frequency stability characterization of external-cavity diode lasers stabilized onto the $6S_{1/2} - 7P_{1/2}$ transition of Cs atom at 459 nm, using a microfabricated vapor cell, in a basic retroreflected configuration saturated absorption spectroscopy setup (see Fig. 1). The laser beatnote obtained between two quasi-identical systems demonstrates an instability of 2.5×10^{-13} at 1s, currently limited by the laser FM noise through the FM-AM conversion process and the intermodulation effect, and in good agreement with the noise budget [5]. The stability averages down at the level of 4×10^{-14} at 100 s. Sensitivity coefficients of the laser beatnote frequency to the laser power at the cell input and cell temperature variations are currently being measured. The latest results will be presented at the conference.

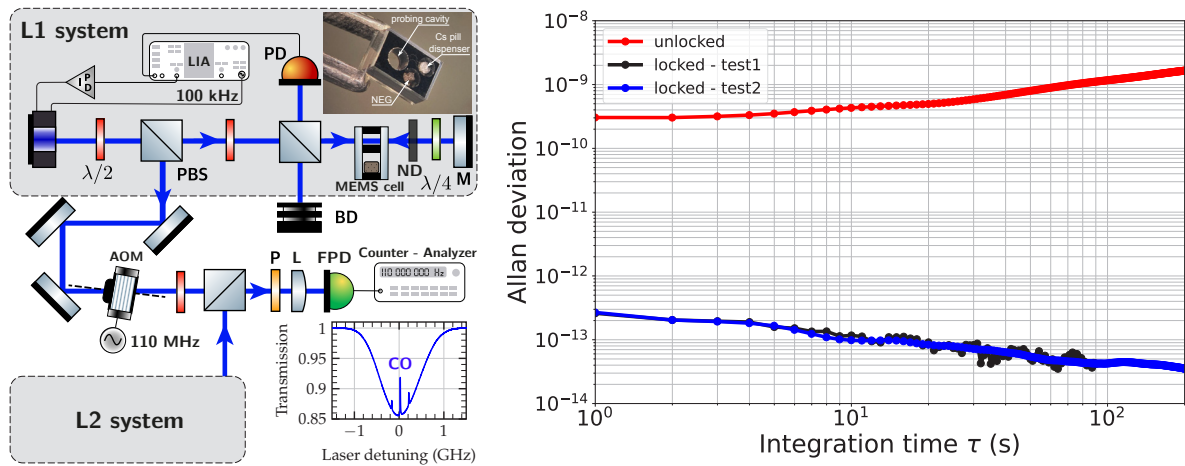


Fig. 1: Two lasers, tuned at 459 nm, are stabilized onto a Cs vapor microfabricated cell in a simple SAS configuration. The frequency of the first laser is shifted by 110 MHz using an acousto-optic modulator to create a beatnote between the two quasi-identical systems. When both lasers are locked, the beatnote demonstrates an instability of 2.5×10^{-13} at 1 s and 4×10^{-14} at 100 s.

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Thu – 47

Josephson dynamics of one-dimensional ultradilute quantum liquids**Marek Tylutki^{*1}, Piotr Wysocki^{2,1}, Krzysztof Jachymski², Grigori E. Astrakharchik³**¹Faculty of Physics, Warsaw University of Technology, Ulica Koszykowa 75, PL-00662 Warsaw, Poland²Faculty of Physics, University of Warsaw, Pasteura 5, PL-02093 Warsaw, Poland³Departament de Física, Universitat Politècnica de Catalunya, E-08034 Barcelona, Spain

The progress in cooling and control of ultracold quantum gases and their mixtures has allowed for engineering new states of matter in laboratories. For example, such system could be an ultradilute quantum liquid in a binary mixture of Bose-Einstein condensates [1], where a low compressibility favours constant bulk density and allows for formation of finite-size quantum droplets. We study one-dimensional ultradilute quantum liquids in the context of their collective excitations and Josephson dynamics. The Josephson oscillations are characterized by dynamics that differs from that of a single-component Bose-Einstein condensate and is characterized by non-linear localization revivals [2].

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Poster sessions

Thursday

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The entanglement and Legget-Garg inequality in a two-mode bosonic system.

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We consider a model consisting of quantum nonlinear oscillators that are mutually coupled and continuously driven by an external coherent EM field. For such a model, we focus on temporal correlations and investigate the violation of the Leggett-Garg Inequality (LGI). By analyzing different measurement scenarios based on projection onto different Bell states, we show that the possibility of violating the LGI is related to the use of different projectors.



Resonances in quantum waveguides systems

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We present the study of various two- and three-dimensional non-relativistic quantum systems with asymptotically straight so called "soft waveguides". We focus on locally deformed symmetric waveguides and show that embedded eigenvalues become resonances under weak deformation. We analyze the asymptotic behavior of the corresponding complex poles as a function of the deformation.

We consider also a two-dimensional waveguide with a transversally invariant profile and a perturbation located at distance r . Under suitable assumptions, the resolvent exhibits a second-sheet pole at $z(r)$, whose imaginary part satisfies Fermi's golden rule, which we explicitly derive.

We present also the studies of Dirichlet waveguides in $\mathbf{R}^n$ ($n=2,3$) with an attached cavity. We show how the characteristics of resonances depends of a small gap in the cavity.

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